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FUNDAMENTAL PROBLEMS IN COLOR VISION. I. THE PRINCIPLE GOVERNING CHANGES IN HUE, SATURATION, AND LIGHTNESS OF NON-SELECTIVE SAMPLES IN CHROMATIC ILLUMINATION

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For almost three decades chief interest in the psychology of color has centered in the problem of color constancy and the questions associated with it. While numerous investigations have been made regarding the conditions and extent of constancy and its relation to contrast, adaptation, and modes of appearance, only a few studies have been devoted to the changes in color which objects undergo in strongly chromatic illumination after constancy has disappeared. In spite of the large number of observations and theories concerning the perseveration of 'normal' or daylight color with changes in illumination, no satisfactory principles have been formulated which relate object color and illuminant color or which give a satisfactory account of the relations between contrast, constancy, and adaptation.

In seeking an answer to the general question: Given any object as stimulus, what will be its hue, saturation, and lightness when viewed on any background under any illuminant? —we have succeeded in formulating a principle which embraces constancy, contrast, adaptation and other phenomena related to them. The changes in any attributes of color which

occur with changes in illumination, background or any of the conditions of viewing we call 'color conversion.'[1] Constancy has emerged as a special case of conversion which is the more general and more fundamental problem.

Among the conditions which must be controlled and investigated in any study of color conversion the following are most important: (1) composition and intensity of illumination; (2) reflectances of all objects and background in the field of vision; (3) state of the eye and mode of viewing stimuli. In the experiments reported here all of these factors have been controlled and their effects noted. For accurate predictions and hence for a valid theory of color conversion, quantitative data specifying the light beam reaching the eyes as well as reflectances must be known and a mathematical formulation to theory is both desirable and necessary. The discussion of non-selective samples in chromatic illumination is much simpler than that of selective samples because, while the reflectances differ, the trilinear coördinates of non-selective samples are alike and identical with that of the illuminant. We shall therefore restrict ourselves in this article to the case of non-selective samples in chromatic illumination, leaving it for later reports to take up selective samples and the mathematical formulation [2] of the principle discussed qualitatively in this paper.

Definition of Terms

Definition of Terms.—In order to avoid ambiguity and confusion the chief technical terms used in this and succeeding papers will be defined in accordance with the usage prevailing in the fields from which they are taken.

Color: the quality of any visual experience except its spatial attribute of extent or bulk. Here we include both the chromatic and achromatic hues and all dimensions usually ascribed to the color for a given mode of viewing, *e.g.*, hue,

[1] This term was first used in a paper presented at the Dartmouth meetings of the American Psychological Association in 1936 (Helson and Judd, 11).

[2] Judd (21) has proposed formulæ for hue, lightness, and saturation of surface colors which will be discussed in a later paper.

saturation and brightness for aperture (film) colors, and, in addition, pronouncedness, *etc.*, for surface colors.

Surface color: a color belonging to a surface and viewed in unrestricted vision. As described by Katz, surface colors are hard, resist the gaze, inhere in the plane of the object, reveal the microstructure of the object, and have the attribute of pronouncedness in addition to the classical dimensions now restricted to

Aperture color: a color seen at an indefinite distance behind a small aperture in a non-selective material used as a screen. The color thus seen is soft, filmy, penetrated by the gaze, lies in the frontal-parallel plane and has hue, brightness and saturation. It is assumed that the aperture is a small hole in a '*black*' *screen upon which no light is falling.*

Lightness: used for object colors in preference to the common terms brilliance, brightness or tint which are reserved for the aperture mode of viewing. Very light surface colors approach white but no whites are found in the aperture mode.

Achromatic colors: colors lacking hue in the sense of members of the brilliance or black-white series of colors. It should be noted that objects achromatic in one illumination are not necessarily so in another and hence the need to refer to

Selective and non-selective samples: samples whose spectral reflectance is constant throughout the visible range are said to be non-selective and to have non-selective reflectance. Such samples are achromatic, as a rule, but it should be noted that they are not necessarily achromatic at all times. They may be highly saturated, as the present study will show. On the other hand, selective samples may be achromatic in certain illuminations. Chromaticity and achromaticity refer to color as experienced, selectivity and non-selectivity to the physical properties of the sample.

Reflectance: an abbreviation in the present work for the term, apparent reflectance, defined as the fraction of the incident light which an hypothetical perfectly diffusing sample would need to reflect in order to yield the same brightness as the actual sample under the same conditions of illuminating and viewing. The spectral characteristics of the illuminant

have usually to be given, thus: reflectance for incandescent lamp light, or daylight reflectance, or reflectance for artificial sunlight and so on. When the sample is measured in the spectrophotometer wavelength by wavelength, its *spectral reflectance* is determined.

Tristimulus specification: a way of specifying any color-stimulus by stating the amounts of three arbitrarily chosen primaries (not necessarily real color stimuli) which, when mixed, result in a match for the color in question. Such specification does not require actual matching if the spectral composition of the light source, transmission of filters, and spectral reflectances of the sample are all known—in which case the tristimulus values can be calculated (*Cf.* Judd, **19**).

Trilinear coördinates: the amounts of the three primary stimuli necessary for matching any stimulus given as percentages. Since they add to 100 percent, only two of the three values need be stated. Trilinear coördinates differ according to the system employed. In our work the U.C.S. system, developed by Judd, will be used and all specifications will refer to the U.C.S. triangular mixture diagram (Judd, **20**).

Conversion: a term introduced by the present writer to denote *any change in color* due to any circumstances whatsoever, *e.g.*, to change in spectral character of the illuminant, to change in background or in neighboring samples, or to change in state of the viewing mechanism. It includes changes which both selective and non-selective samples undergo when the illuminant changes from, say, daylight to strongly chromatic illumination. The term does not imply that any illuminant or particular conditions of viewing are standard. Conversion refers to the change in color which any object undergoes in time or place.

Transformation: a term used by some writers to express the fact that object color under non-daylight or some similar illumination or in shadow or through some other change in conditions is transformed from the aperture color derived from the object color usually to daylight color. Since oftentimes conversion is nearly back to daylight color, some writers have used this term as a substitute for constancy.

Sample: this term will be used in preference to the terms 'stimulus' and 'object' because of the particular stimuli used in this work—Munsell paper samples.

Ground and background: these words will be used interchangeably for the parts of the field on which the samples appeared and for the walls of the light booth which, at least within the field of vision, were like the ground on which the samples appeared.

Experimental Conditions, Procedure and Subjects' Reports

The experiments, ranging over a period of five years and employing several experimenters and different sets of subjects (denoted by *S*), were all conducted in a light-tight booth specially constructed for the purpose (Fig. 1). The booth consisted of a wooden structure $6' \times 6' \times 7'$ erected in a dark room of the laboratory and lined with white and gray cardboard as shown in Fig. 1. When a 'gray' or 'black' ground was desired the walls in the field of view were changed accordingly. In one corner of the booth was a shelf (*S*, Fig. 1), on which the samples were placed. In the ceiling of the booth were two apertures, one of which (F.L.) admitted only filtered light from the light source, the other, when used with the MgO reflector, admitted light from the 2850° K. source through the aperture marked W.L. in Fig. 1. The openings just described were $6'' \times 6''$ and so made that filters and screens could be inserted to change the composition or intensity of light in any manner desired. The light source was a 500-watt Mazda lamp, calibrated and loaned by the National Bureau of Standards. It was equivalent to a black body radiator of 2850° K. when operated at 103 volts. The resistance and voltmeter (*M*) enabled us to maintain constant operating conditions. When we wished to mix light from the source which was nearly achromatic with the strongly chromatic illumination from the filters, the second opening was used with the MgO reflector placed at an angle of 45° to the source and to the aperture. A ground glass (G.G.) was placed under the two openings and above the samples to diffuse the light entering the booth and to insure uniform illumination on the samples.

The stimuli consisted of 16 samples from the Hering series of grays and a white, gray and black identical with the backgrounds, the latter having reflectances of .80, .23 and .03 respectively. The samples were 40×50 mm and were placed in holders to keep them flat and clean. These were identical with the backgrounds and the margin of 14.5 mm of holder around each sample served to separate the samples from each other and to insure uniform background effects. The samples seemed to be sufficiently closely non-selective to make measurements of spectral reflectance unnecessary. Observation under daylight illumination resulted in agreement among all Ss that all samples were achromatic. Reflectance for incandescent-lamp light was measured by means of the Macbeth illuminometer and is given in Table 4 under R. While the samples are arranged in the table in order of reflectance, during observations they were placed in haphazard order for viewing.

The trilinear coördinates of the illuminants, backgrounds, and samples are assumed to be identical and are given in Table 1. The spectral composition of the source was

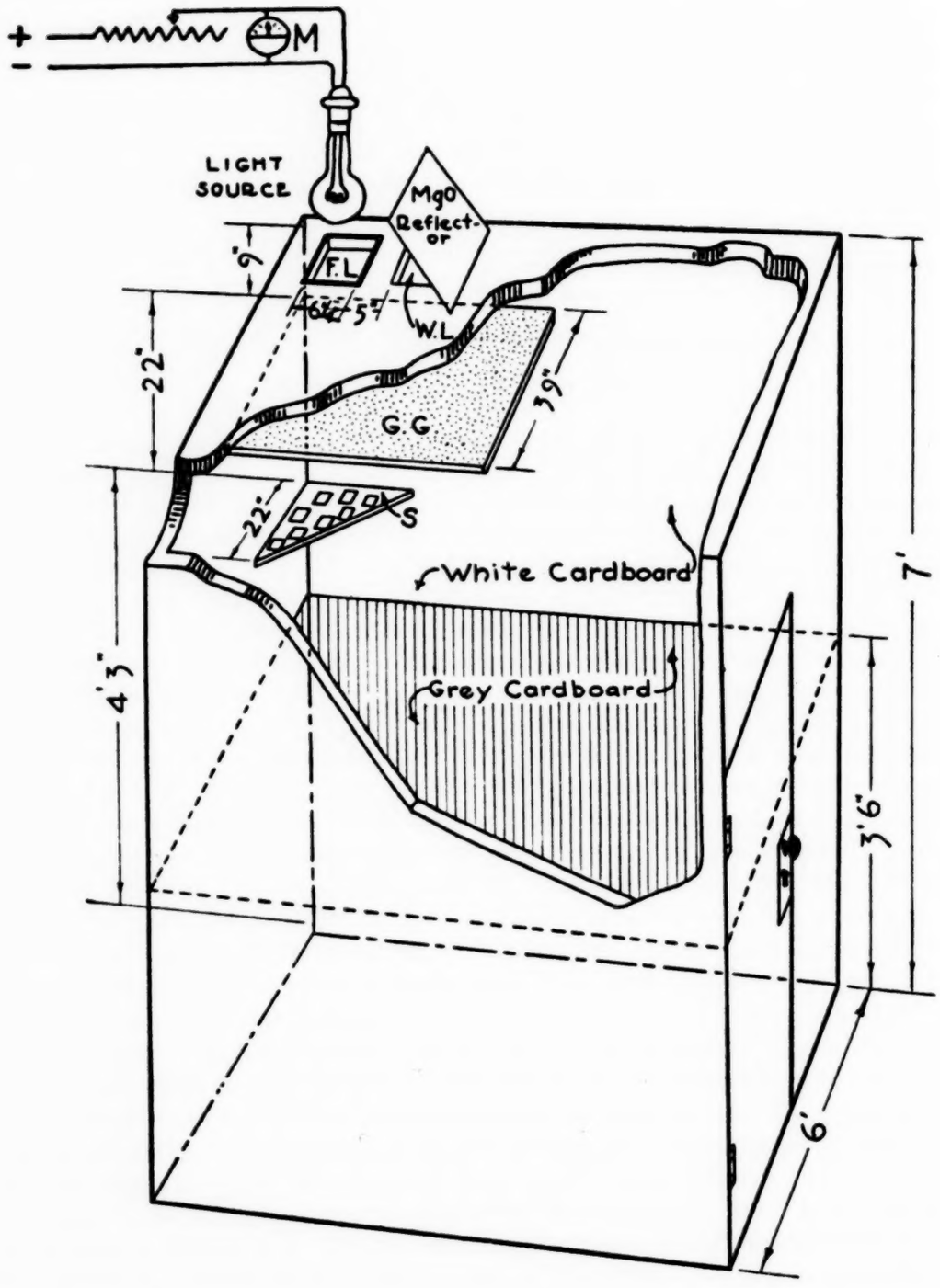

FIG. 1. The color booth. Light from the 2850° K. source enters the booth through filters placed in the opening F.L. and is diffused by the ground glass G.G. before reaching the sample plane *S*. White light is introduced through the opening W.L. when desired. Non-selective filters were used in F.L. and W.L. to reduce the intensity of illumination. The MgO reflector served to increase the amount of white light through W.L.

TABLE 1

THE TRILINEAR COÖRDINATES (U. C. S. SYSTEM) OF THE SOURCE-FILTER COMBINATION OR ILLUMINANT, SAMPLES AND BACKGROUNDS

Red		Yellow		Green		Blue	
r	g	r	g	r	g	r	g
.958	.042	.705	.295	.372	.613	.237	.351

known through its equivalence with a black body radiator of 2850° K. and the spectral transmissions of the filters were determined spectrophotometrically. From these two sets of values the trilinear coördinates can be computed and it is found when they are plotted on the color triangle that the red illuminant is identical with 643 mμ in the spectrum, while the other illuminants are close to 596 mμ (yellow), 546 mμ (green), and 461 mμ (blue).

In addition to the specifications already given of our illuminants the illuminant colors should be stated qualitatively so that our results may be intelligible on the psychological level. While we refer to the filters as red, yellow, green, and blue, light samples in the field tended to show additional components as given in Table 2.

TABLE 2

SHOWING THE HUES OF THE FILTERS, THE HUES OF THE ILLUMINANTS WHEN THE FILTERS ARE USED WITH A SOURCE OF 2850° K., AND THE MIXTURE AND AFTER-IMAGE COMPLEMENTARIES OF THE ILLUMINANT HUES

Filter Hue	Illuminant Hue	Mixture Complementary	After-image Complementary
R	R or yR	bG	gB
rY	Y	B	rB
G	yG	bR	BR
B	B or rB	Y	RY or yR

Furthermore, the distinction between hues of complementary colors as given by mixture and in the after-image is necessary and made clear in Table 2 where it will be seen that the after-image complementary differs from the mixture complementary in having more red-blue, as Tschermak (42) has pointed out. Our results are explicable in terms of after-image complementarism and throughout this work when speaking of complementary colors we shall always mean the after-image complementary and not the mixture complementary.

It will be seen that three of our illuminants were good unitary colors but the other one, as judged by the reports on the light samples, contained a yellow component. The difference between the mixture and after-image complementaries is very striking and is important when we come to the discussion of results and formulation of a general principle of conversion.

Having standardized conditions so far as the stimuli were concerned, the next task was to make sure that Ss reported accurately the hues, lightnesses and saturations of the colors in the sample plane. Often Ss enter color experiments without knowledge or practise in identifying and ordering colors with respect to these three fundamental

attributes. Undoubtedly much of the variability and difficulty in reporting referred to in the literature springs from the fact that Ss are not trained for the specific task in question, not to mention equivocal conditions on the stimulus side. Our Ss were shown the Munsell book of color and trained to recognize and report upon differences in the three fundamental dimensions. No attempt was made to get reports on pronouncedness, microstructure, or other surface attributes. This training was given *before* entering the color booth; results after the experiments in the booth were begun were accepted without question. We owe much to this preliminary training and believe that if reproducible results and scientific hypotheses are to be formulated both stimulus and S must be 'standardized.' On the other hand, our results with trained Ss have been verified by untrained individuals and visiting psychologists who have merely observed in the color booth *en passant*.

In many of the experiments reported in the literature it is impossible to determine what was actually acting as stimulus. The customary set-up for constancy experiments in which one field is 'normally' illuminated and the other is 'shadowed' or otherwise different from the first involves vision now in one illumination, now in another. Both the difficulty of observing and the unreliability of results attest the shortcomings of conditions in which the state of the eye is either not definitely controlled or is subject to rapid changes. Our Ss were in a single illumination and in the same illumination as the samples. The importance of a known, unitary lighting situation cannot be over-emphasized. Our results show that failure to control background, sample, illuminant or the adaptation of the eye introduces serious sources of error. In particular we have found it necessary to confine our experiments to nearly equilibrium adaptive states of the eye; the temporal course of adaptation is considerably more complicated than the near-equilibrium state which we have studied. It is hard to see much value in speculations about mechanisms responsible for conversion which are based on experimental results with any of these conditions uncontrolled.

Judgments of hue were made with respect to a sixteen-fold classification as follows: the primary hues were called red, green, yellow, and blue, while members of the gray series were called achromatic. Unitary colors were given one name and binary colors were given a double name, *e.g.*, Red-Blue or Yellow-Green. If one component predominated the adjectival form was used for the minor component, *e.g.*, yellowish-Green, bluish-Red. Abbreviations utilize small letters for the minor component and capitals for the predominating hue, *e.g.*, yG, bR. The first hue in the compound noun form does not mean that it predominated, *i.e.*, RB and BR are identical.

Reports on saturation and lightness were based on an arbitrary 10-point scale in which 10 denoted maximum lightness or saturation and 0 a minimum. The Munsell notation was used, the numerator referring to lightness, the denominator to saturation. Thus R 6/4 refers to a red having a lightness a little above medium and a saturation a little below. The notation for white would thus be A (achromatic) 10/0 and for black, A 0/0. Some objections can be raised to our attempt to quantify or order in this manner. While some Ss gave the lightest color in the field or the most saturated one the maximum value of 10, others seemed to have an absolute standard apart from the viewing conditions so that the lighest or most saturated color received a value less than 10. Furthermore although subsequent direct comparison of samples on 'white' and 'black' grounds showed the latter to be lighter and more saturated, the values given to them were not, in general, higher when viewed on the 'black' ground because the Ss could not give a value greater than 10 and did not attempt to base their values upon memories of colors obtained with different backgrounds.

The intensities of illumination were not the same for the four illuminants owing to the differences in transmissions of the four filters employed. This variation in conditions was more than offset by two facts: intensity differences within a very wide range were found to be of minor importance, something we shall discuss in a later section; observations were made with four different intensities the ratio of highest to lowest being 96 : 1. Each illuminant was therefore used throughout a sufficiently wide range of intensities to reveal effects of intensity differences if any. Unless otherwise stated all results refer to the medium range of intensity for each filter. Three of the four intensities employed are given in Table 3 as well as the transmissions

TABLE 3

SHOWING THE TRANSMISSIONS OF THE FOUR FILTERS FOR 2850° K., THE INTENSITY (I) IN FOOT CANDLES (f.c.) ON THE SAMPLE PLANE FOR EACH SOURCE-FILTER COMBINATION AT THREE INTENSITIES

Filter	Transmissions for 2850° K.	Low I (f.c.)	Medium I (f.c.)	High I (f.c.)
None	1.000	1.4	72.0	135.0
Red	0.052	0.073	3.7	7.0
Yellow	0.362	0.510	26.0	49.0
Green	0.038	0.058	2.7	5.1
Blue	0.0061	0.0085	0.44	0.82

of the filters. From this table it will be seen that the yellow filter has the highest transmission for incandescent-lamp light and the blue the lowest. The highest intensity of the blue (.82 f.c.) is 1.6 times the lowest for the yellow (.51 f.c.) illuminant.

Increase in intensity was achieved by the use of a reflector over the source and decrease by interposing non-selective filters or screens between the source and the filters. Calculation of the brightness on the sample plane consisted simply in multiplying the illumination in apparent foot candles on the sample plane without filters by the transmissions of the filters, thus avoiding heterochromatic photometry.

Returning to the procedure used in the experiments we may note that each S was given 15 minutes' adaptation to the illumination before the samples were exposed. The field in front of S was lined with 'white' cardboard during the adaptation period regardless of the background used in the observations which followed. The 'white' background and the fifteen minutes' adaptation insured complete adaptation to the illumination. Ss were instructed to allow their eyes to wander over the samples without resting too long on any one as they made their judgments of hue, lightness and saturation. S's voice could be heard outside the booth by the experimenter who could thus take down the protocols without being seen. Twenty-seven individuals acted as Ss altogether though space prohibits the use of more than typical individual results or averages.

At this point I am happy to acknowledge with thanks the part of Dr. Deane B. Judd of the National Bureau of Standards and my students Mrs. Virginia Balough Jeffers and Miss Mildred Henrich in this study. Dr. Judd has been in close touch with the work from the beginning as our previous publications together (9, 10) show and he has aided greatly with the loan of the calibrated light source, with measurements of transmission, and in the computation of trilinear coördinates as well as with advice

as to procedure and interpretations. The data in Table 4 and in Figs. 2 and 3 are from experiments carried on by Miss Henrich and those in Tables 6 and 7 are from work by Mrs. Jeffers.

TABLE 4

SHOWING THE REFLECTANCE (R), HUE, LIGHTNESS, AND SATURATION FOR SAMPLES ON THREE BACKGROUNDS IN FOUR DIFFERENT ILLUMINATIONS (SUBJECT 1)

Backgrounds were White (W), Gray (G), and Black (B) in daylight. Numerator indicates lightness and denominator indicates saturation as in the Munsell notation.

R	Red Illuminant			Green Illuminant		
	W Bkgd.	G Bkgd.	B Bkgd.	W Bkgd.	G Bkgd.	B Bkgd.
0.80	R 9.0/0.5	R 8.5/7.0	R 7.0/7.0	YG 9.0/1.0	YG 8.0/7.0	YG 9.0/7.0
.52	R 7.0/1.0	R 7.5/6.0	R 7.0/7.0	YG 8.0/1.0	YG 7.0/5.0	YG 8.0/6.0
.39	A 6.0/0.0	bR 6.0/3.0	R 6.0/7.0	A 7.0/0.0	YG 6.0/3.0	YG 6.0/5.0
.34	A 6.0/0.0	bR 6.0/3.0	R 5.0/5.0	A 7.0/0.0	YG 6.0/3.0	YG 6.0/5.0
.27	B 6.0/1.0	RB 6.0/3.0	bR 5.0/5.0	BR 7.0/1.0	YG 5.5/1.0	yG 5.0/5.0
.23	B 5.0/2.0	RB 5.5/2.0	bR 5.0/5.0	BR 7.0/1.0	YG 5.5/1.0	yG 5.0/5.0
.22	B 5.0/3.0	RB 5.5/2.0	bR 4.5/4.5	BR 7.0/1.0	A 5.0/5.0	yG 4.5/5.0
.17	B 5.0/4.0	RB 5.0/1.0	bR 5.0/4.0	BR 6.0/2.0	A 5.0/0.0	yG 4.5/5.0
.16	B 5.0/4.0	RB 5.0/0.5	bR 4.0/4.0	BR 6.0/3.0	A 5.0/0.0	yG 4.0/5.0
.15	B 5.0/5.0	A 5.0/0.0	bR 4.0/4.0	BR 6.0/3.0	A 4.0/0.0	yG 4.0/5.0
.13	B 5.0/5.0	A 5.0/0.0	bR 4.0/4.0	BR 6.0/3.0	A 4.0/0.0	yG 3.5/4.0
.13	B 5.0/5.0	A 5.0/0.0	bR 3.0/4.0	BR 6.0/3.5	A 4.0/0.0	yG 3.5/4.0
.11	B 5.0/5.0	A 4.0/0.0	bR 3.0/4.0	BR 6.0/3.5	A 4.0/0.0	yG 3.5/4.0
.10	B 5.0/5.0	bG 4.0/0.5	bR 2.0/2.0	BR 5.0/4.0	RB 4.0/2.0	yG 3.0/3.0
.07	B 4.0/6.0	bG 4.0/1.0	bR 1.0/1.0	BR 5.0/5.0	RB 3.0/3.0	yG 2.0/2.0
.07	B 4.0/6.0	bG 3.0/3.0	bR 1.0/1.0	BR 5.0/5.0	RB 3.0/3.0	yG 2.0/2.0
.05	B 4.0/6.0	bG 3.0/3.0	bR 1.0/1.0	BR 4.0/6.0	RB 3.0/4.0	yG 1.0/1.0
.03	gB 4.0/6.0	bG 2.0/5.0	bR 1.0/0.5	BR 3.0/7.0	RB 2.0/5.0	yG 0.5/0.5
.03	BG 3.0/7.0	BG 1.0/8.0	A 0.0/0.0	BR 3.0/8.0	RB 1.5/6.0	A 0.0/0.0

R	Blue Illuminant			Yellow Illuminant		
	W Bkgd.	G Bkgd.	B Bkgd.	W Bkgd.	G Bkgd.	B Bkgd.
0.80	B 9.0/1.0	B 8.0/8.0	B 7.0/6.0	gY 9.0/1.0	Y 8.0/7.0	Y 9.0/7.0
.52	B 7.0/1.0	B 7.0/7.0	B 6.0/5.0	gY 8.0/1.0	Y 7.0/5.0	Y 7.0/5.0
.39	A 6.0/0.0	B 6.0/5.0	B 5.0/5.0	A 7.0/0.0	Y 6.5/3.0	Y 6.0/4.0
.34	rB 6.0/1.0	B 6.0/5.0	B 4.5/5.0	A 7.0/0.0	Y 6.5/2.0	Y 6.0/3.0
.27	rB 5.0/1.0	rB 6.0/2.0	B 4.0/5.0	RB 7.0/2.0	Y 6.0/0.5	Y 5.0/2.0
.23	Y 5.0/1.0	rB 6.0/2.0	B 4.0/5.0	RB 6.0/2.0	Y 6.0/0.5	Y 5.0/2.0
.22	Y 5.0/1.0	rB 5.0/1.0	rB 4.0/4.0	RB 6.0/2.0	A 6.0/0.0	Y 5.0/1.0
.17	Y 5.0/1.0	A 4.0/0.0	rB 3.5/4.0	RB 6.0/3.0	A 5.5/0.0	Y 5.5/1.0
.16	Y 5.0/1.0	A 4.0/0.0	rB 3.5/4.0	RB 6.0/3.0	A 5.0/0.0	Y 5.0/1.0
.15	Y 5.0/1.0	A 4.0/0.0	rB 3.5/4.0	RB 6.0/3.5	A 5.0/0.0	Y 5.0/1.0
.13	Y 4.0/2.0	A 3.5/0.0	rB 3.5/4.0	RB 6.0/3.5	A 5.0/0.0	Y 5.0/1.0
.13	Y 3.0/1.0	A 3.5/0.0	rB 3.5/4.0	RB 6.0/4.0	A 5.0/0.0	Y 5.0/1.0
.11	Y 3.0/1.0	A 3.0/0.0	rB 3.0/4.0	RB 5.0/4.0	RB 4.5/1.0	Y 4.0/1.0
.10	Y 3.0/2.0	Y 2.5/0.5	rB 2.5/3.0	RB 5.0/5.0	RB 4.0/1.5	A 5.0/0.0
.07	Y 4.0/4.0	Y 2.0/2.0	rB 1.0/2.0	RB 4.0/6.0	RB 3.0/2.0	A 3.0/0.0
.07	Y 3.0/3.0	Y 2.0/2.0	RB 1.0/1.0	RB 3.0/6.0	RB 3.0/3.0	A 3.0/0.0
.05	Y 3.0/5.0	Y 2.0/2.0	RB 1.0/1.0	RB 3.0/6.0	RB 3.0/3.0	RB 2.0/2.0
.03	Y 2.0/6.0	RY 1.0/5.0	A 0.5/0.0	RB 3.0/7.0	RB 2.0/5.0	RB 1.0/3.0
.03	Y 2.0/6.0	RY 1.0/5.5	A 0.0/0.0	rB 2.0/8.0	B 1.0/6.0	A 0.0/0.0

The General Principle Governing Constancy, Contrast, Conversion and Adaptation

Inspection of Table 4, in which are given the reflectance, hue, lightness, and saturation of each of the 19 samples in four illuminations and on three different backgrounds, reveals that samples of high reflectance have the illuminant hue, samples of intermediate reflectance are achromatic, and samples of low reflectance have the hue of the after-image complementary to the illuminant hue. These facts are seen best on the 'gray' ground. It will be noticed that the samples reported achromatic are those of higher (but not highest) reflectance on the 'white' ground, but of intermediate reflectance on the 'gray' ground, and of lowest reflectance on the 'black' ground. From this we may conclude that, other things being equal, the background reflectance is the most important factor determining the adaptation level and hence the colors of samples appearing on it. While adaptation did not render all non-selective samples achromatic in homogeneous illumination, as Koffka (**27, 28**) has asserted should be the case under our conditions, it did result in the establishment of what we shall call an adaptation reflectance which is in reality a range of reflectances such that samples whose reflectance coincides with or are near it are achromatic. The adaptation reflectance determines not only which samples shall remain achromatic, hence constant, but which shall take on either the illuminant color or its complementary.

We can now formulate the general principle governing constancy, conversion, contrast and adaptation in chromatic illumination: *samples above the adaptation reflectance take the hue of the illuminant color; samples below it, the hue complementary to the illuminant hue; while samples near the adaptation reflectance are either achromatic or greatly reduced in saturation.*[3] In formulating this principle we have made but one assump-

[3] The following quotation from Bühler shows an implicit recognition of this principle although it is never expressed or made use of by either Bühler or his students in writing on the effects of chromatic illumination: "Certainly," says Bühler (**4**, p. 99), "even in bright sunlight colors change. There are no perfect papers for . . . even the purest white paper becomes yellowish in sunlight while the intruding shadows make 'all cats' gray-black with a bluish tinge."

tion which concerns the establishment of an achromatic point with reference to which constancy, illuminant color and complementary color are to be explained. Providing the eye is exposed to a single illumination no further assumptions are necessary for the facts in question.

This general principle is based upon the time-honored and widespread view (Katz, **26**, Kravkov and Paulsen-Baschmakowa, **34**, Mach, **36**, Hess and Pretori, **13**, Kohlrausch, **30**, and Kardos, **24**) that object color depends upon the ratios of light reflected from the various parts of the visual field rather than on the absolute amounts. Particularly this formulation is foreshadowed by Kardos (**24**) who suggested as a condition for object-color constancy the constancy of the ratio of the light reflected by the object to that reflected by the ground. Our general principle is a refinement of this view and relates it to the problem of vision in chromatic illumination.

To explain the typical results in Table 4 it is unnecessary to postulate parallel processes for constancy and contrast in the sense of Jaensch (**14**, **15**, and Jaensch and Müller, **17**, and Jaensch and Wiegand, **18**), to invoke a 'noticing of the illumination' in the sense of Katz (**26**) to explain constancy, or to assume a 'discounting of the illumination' as Jaensch has done (**16**) to explain the same fact. Nor is it necessary to assume a 'shift in level' for the explanation of constancy and a different principle, namely that of color difference, as Koffka (**27**) has done, for contrast, since the relation of sample reflectance to adaptation reflectance explains all the facts without special assumptions regarding any particular ones.[4] The appearance of illuminant color, complementary color, and constancy under one set of conditions forces us to the conclusion a single mechanism must be responsible for all.

Several important phenomena evident in our results and characteristic of chromatic illumination deserve special consideration. First, it will be noticed that samples having the lowest saturation are those near the adaptation reflectance

[4] No summary of experiments or theories in the field of constancy can be attempted in this paper and so the reader is referred to the excellent historical discussions to be found in MacLeod (**37**) and Henneman (**12**).

which changes with reflectance of the background. Under our conditions of strongly chromatic illumination the lightest and darkest samples have the greatest saturations, contrary to the usual view regarding the lightness-saturation relationship. This fact has been noted by Bocksch and Krauss (**1**, **31**) for light samples who called it the *Aufweissung* effect but who did not report an analogous effect for samples whose reflectances are below the adaptation reflectance which become more saturated with the complementary hue the greater the difference between their reflectance and the adaptation reflectance. The color pyramid which represents the relationship as one of decreasing saturation with either increasing or decreasing lightness as colors depart from medium lightness is therefore not a correct representation of the facts in strongly chromatic illumination. This phenomenon also contradicts theories which postulate decreasing chromas with very high or very low lightnesses and serves to give Ss the impression that colors in strongly chromatic illumination are different from any seen under ordinary conditions.

A second phenomenon deserving special mention concerns the change in hue of samples whose reflectances are below the adaptation reflectance. Inspection of the hues reported on the 'white' ground (Table 4) reveals that samples darker than the achromatic ones have a red or blue component in addition to the mixture complementary component, the former often appearing before the latter. That the red or blue components may appear before the mixture component, *e.g.*, B in the red illuminant before gB, and RB before rB or B in the yellow illuminant appears in Table 4. It is as if the mixture complementary had greater difficulty in overcoming the illuminant hue and hence appears later when conditions are most favorable, whereas the R or B component, when it does not have to cancel the illuminant hue, appears under less favorable circumstances. Furthermore, a fact which cannot appear in the results for only one S, either R or B may appear first, depending upon the individual S. The relative strength of the R and B components of the after-image complementary seems to be an individual matter.

Thirdly, the results in Table 4 show that mere change in background is sufficient to change the hues of practically all the samples. What will be constant, what will take on the illuminant or complementary color, depends upon its relation to the background reflectance. Attempts to formulate general principles regarding the change of hue which objects undergo in chromatic illumination without relating object reflectance to reflectances of all other samples and background reflectance have only succeeded in giving partial truths valid only for the particular background used in the theorists' experiments. That various writers have not realized the importance of background reflectance is clear from their discussions of constancy and color changes in chromatic illuminations.

A fourth important finding concerns the adaptation reflectance or achromatic point in the reflectance series. According to the view of Jaensch (**14**, **15**) and Koffka (**27**, **28**) the achromatic level established in chromatic illumination represents a shift from an hypothetical 'normal' or daylight illumination but our findings indicate and our theory assumes that the achromatic point is established with reference to the conditions obtaining *within* the viewing situation itself and is a function of the weighted average reflectances of samples and background. The concept of 'change in level' as used by Koffka seems to mean that the background becomes completely achromatic in chromatic illumination. No reference is made to the fact that the adaptation level established under various conditions may be anyplace along the light-dark continuum, *i.e.*, high, medium or low. Koffka erroneously assumes that both non-selective backgrounds and samples will be achromatic in strongly chromatic illumination. According to our principle the achromatic point does not necessarily coincide with either any sample or the background unless there happens to be present a reflectance coinciding with the adaptation reflectance. Whether or not the background is achromatic depends upon its relation to the adaptation reflectance like any sample. Backgrounds of high reflectance certainly do not become achromatic in homogeneous illumination—a

generalization which holds not only for non-selective but for selective backgrounds equally.

We have now to discuss the all-important concept of adaptation reflectance. Adaptation reflectance seems from our results to be an average of the reflectances of the surfaces of which the sample plane is composed; these surfaces should be weighted according to proximity to the fixation point in space and in past time. Many different elements of the viewing situation have to be taken into account in the computation of this weighted mean. Of first importance is the reflectance of the background because most of the sample plane is occupied by the background; of secondary importance is the average reflectance of all samples in the field (Henneman, **12**) and since this average should weight most heavily the samples which have just been fixated, the arrangement of the samples, their size and distance from each other, have their effect.[5] The reflectances meant are the reflectances for the particular illuminant used, and if the samples or background are themselves selective the spectral selectivity of the illuminant is very important. Thirdly, eye-movements determine the weighting of the sample-plane elements in past time and determine the question, important for selective samples, whether the sample is imaged on or off the pigmented portion (macula lutea) of the retina. However fairly reliable computations of adaptation reflectance may be made simply from the reflectance of the ground, A_0, and the logarithmic average, $\bar{A}$, of the sample reflectances. Judd (**21**) has proposed $(A_0^3\bar{A})^{1/4}$ as a first approximation to adaptation reflectance, A'. Furthermore he has proposed the following formula for lightness (L) of any sample on any background:

$$L = \frac{10}{10 - 0.3} \cdot \frac{(10\,A - 0.3)\,(A' + 1)}{A' + A}, \qquad (1)$$

where A is the apparent reflectance of the sample whose lightness is to be predicted and the other symbols have the meanings given them in the discussion preceding the formula.

[5] J. Köhler (**29**, pp. 450 ff.) found that the ground in the neighborhood of the sample is by far the most important.

This formula was devised for such a scale as was used in these experiments, *i.e.*, a 10-point scale in which 0 denoted 'black' and 10 'white' or a maximum of lightness.

From (1) it is seen that the background reflectance receives greatest weight and is the chief factor in the determination of adaptation reflectance. Since we are interested at this point only in the correct evaluation of the adaptation reflectance the values given in Table 5 are of interest. Here are

TABLE 5

SHOWING THE AVERAGE LIGHTNESSES FOR SIX Ss OF SAMPLES REPORTED ACHROMATIC ON THREE BACKGROUNDS IN FOUR ILLUMINANTS AND THE ADAPTATION LIGHTNESS CALCULATED BY JUDD'S FORMULÆ

Bckgd.	Illuminants					Calculated	
	Red	Yellow	Green	Blue	All	$A' = (A_0{}^3\bar{A})^{1/4}$	$A' = 4/5(A_0{}^3\bar{A})^{1/4}$
White.....	7.00	7.10	7.5	7.0	7.1	7.2	6.6
Gray.....	4.7	5.5	5.1	4.0	4.8	5.5	4.9
Black.....	0.0	0.2	1.2	1.3	0.4	1.6	0.6

given the average lightnesses in each illuminant for six Ss of samples reported achromatic on each of three backgrounds and the calculated lightnesses corresponding to achromaticity for each background. The close agreement between observed and calculated values bears out the correctness of assigning predominant weight to background reflectance in calculating the adaptation reflectance.

The discrepancies between observed and calculated adaptation lightness are no greater than 1.2 steps in the 10-step lightness scale. Although the uncertainty of the observed average value is about as large as the discrepancy in each case, from the consistently high calculated values it may be concluded that the adaptation reflectance for our conditions is probably some fraction, say 4/5, of the function proposed by Judd (*Cf.* values in last colum of Table 5). This conclusion is consistent with the finding by Helson and Judd (**10**) that a uniform chromatic field loses all saturation only under extreme and exceptional adaptation.

Effect of Background on Color of Samples

The average lightness of samples reported achromatic on both the 'black' and 'gray' grounds coincided fairly closely with the lightness of the backgrounds themselves, showing that adaptation rendered the backgrounds achromatic in these cases. But in the case of the 'white' ground the average lightness reported achromatic was considerably below the background lightness, 7.15 against 10.0. It appears, therefore, that when the background reflectance is too high adaptation cannot compensate sufficiently to render it achromatic. The result is that samples near the ground and the ground are reported chromatic. In any case, the effect of the ground on the adaptation reflectance and hence on the hue and saturation of all samples in the field appears clearly in Table 4 in the results for different backgrounds, identical samples having different hues on different grounds.

Since there can be no samples darker than the darkest ground, *i.e.*, 'black,' we do not expect complementary colors to appear when this ground is used and Table 4 bears out this deduction from our principle. *The 'black' ground thus has the effect of inducing the hue of the illuminant on all samples* and it may be regarded as doing so through the lightening effect expected from a ground darker than the samples on it. This explains the fact so often reported in the literature that in spectrally homogeneous illumination, or something approaching this, only the color of the illuminant appeared. In some cases it is stated that samples were placed on a black ground (Falkenberg, **6**, and Krauss, **31**) though the writers seem to be unaware of its effect while in others we know such must have been the case from the results reported (Katz, **26**): that objects were tinted with the illuminant color.

Following the implications of our principle for 'white' ground, we expect all samples below the adaptation reflectance to take the hue of the complementary to the illuminant and the results in Table 4 for 'white' ground bear this out. Some Ss, to be sure, report the lighter samples as achromatic on 'white' ground with no reports on illuminant hue, while others

may report the lightest samples as having the illuminant hue, but the majority of the reports contain the complementary. Since the adaptation reflectance on 'white' ground is somewhat below the reflectance of the ground we expect some reports of illuminant hue as some samples have reflectances above the adaptation reflectance though not above the ground reflectance.

Our results with 'white' ground are similar to the findings of several workers whose generalizations regarding the effects of chromatic illumination indicate they must have been working with grounds of high reflectance or with samples of lower reflectance than their grounds. Their generalizations have been denied by others working with darker grounds who found only the illuminant hue! Thus Kravkov (**33, 35**) says that in chromatic illumination the illuminant color calls forth a color tending to neutralize itself. This generalization is true for 'white' or light grounds but false for 'black' or very dark grounds and only half true for 'gray' grounds as our results for 'gray' ground in Table 4 prove. The statement of Bocksch (**2**) that it is impossible to see a sample whose daylight color is green as green in red illumination is in direct contradiction to Kravkov's findings and shows that he must have been using green samples of reflectance higher than the adaptation reflectance under his conditions. Had he used a green sample of low reflectance for red light on 'white' ground his generalization would not have been made. These are but two examples of contradictory generalizations due to the neglect of sample and background reflectances.

We have now only to point out that on 'gray' ground we see illuminant hues, achromatic colors, and complementary hues (Table 4) as we should expect from our principle when the adaptation reflectance is intermediate between the reflectances of the lightest and darkest samples. If samples on 'gray' ground have reflectances no higher than that of the ground, we would not expect the illuminant hue to be seen; similarly, if samples have reflectances no lower than that of the ground we would not expect the complementary hue to be seen. Through its splitting effect on the 'black-white'

series, since the 'gray' ground is lighter than some of the samples and darker than others, it provides the best condition for observing all phenomena possible in chromatic illumination. It is due to the use of grounds of either too high or too low reflectance or of samples at one or the other end of the lightness continuum that workers have made generalizations true only for their own conditions and inadequate for the others. With 'gray' ground and wide range of sample reflectances all the possibilities can be realized simultaneously.

In closing the discussion of background effects we must point out that often effects attributed to 'the presence of other objects in the field' (Henneman, **12**) and to unnamed 'organizational' factors (Burzlaff, **5**) can probably be ascribed to changes in adaptation reflectance caused by variation in object and background reflectances.

Relationships between Lightness, Saturation, and Hue

From our discussion of the general principle underlying color conversions it is evident that certain relationships should be found between the lightness and saturation and between the lightness and hue of any sample in any illuminant. Figures 2 and 3 show even more strikingly than Table 4 how increase in lightness is accompanied by increase in saturation above the achromatic point while decrease in lightness below the achromatic point is accompanied by increase in saturation. Figure 2 contains the plots of samples on 'white' ground (open squares and circles) and on 'black' ground (solid squares and circles). From Fig. 2 it is seen that samples on 'white' ground lie mostly in the quadrant for the complementary hue while those on 'black' ground lie mostly in the portion of the graph for illuminant hue. Figure 3, showing samples on 'gray' ground, brings out the splitting effect on hue of this ground, about half of the samples lying in the illuminant quadrant and the rest in the complementary region. The curves for 'gray' ground might be regarded as a combination of the curves for the corresponding 'black' and 'white' grounds. All the curves show that, contrary to the usual

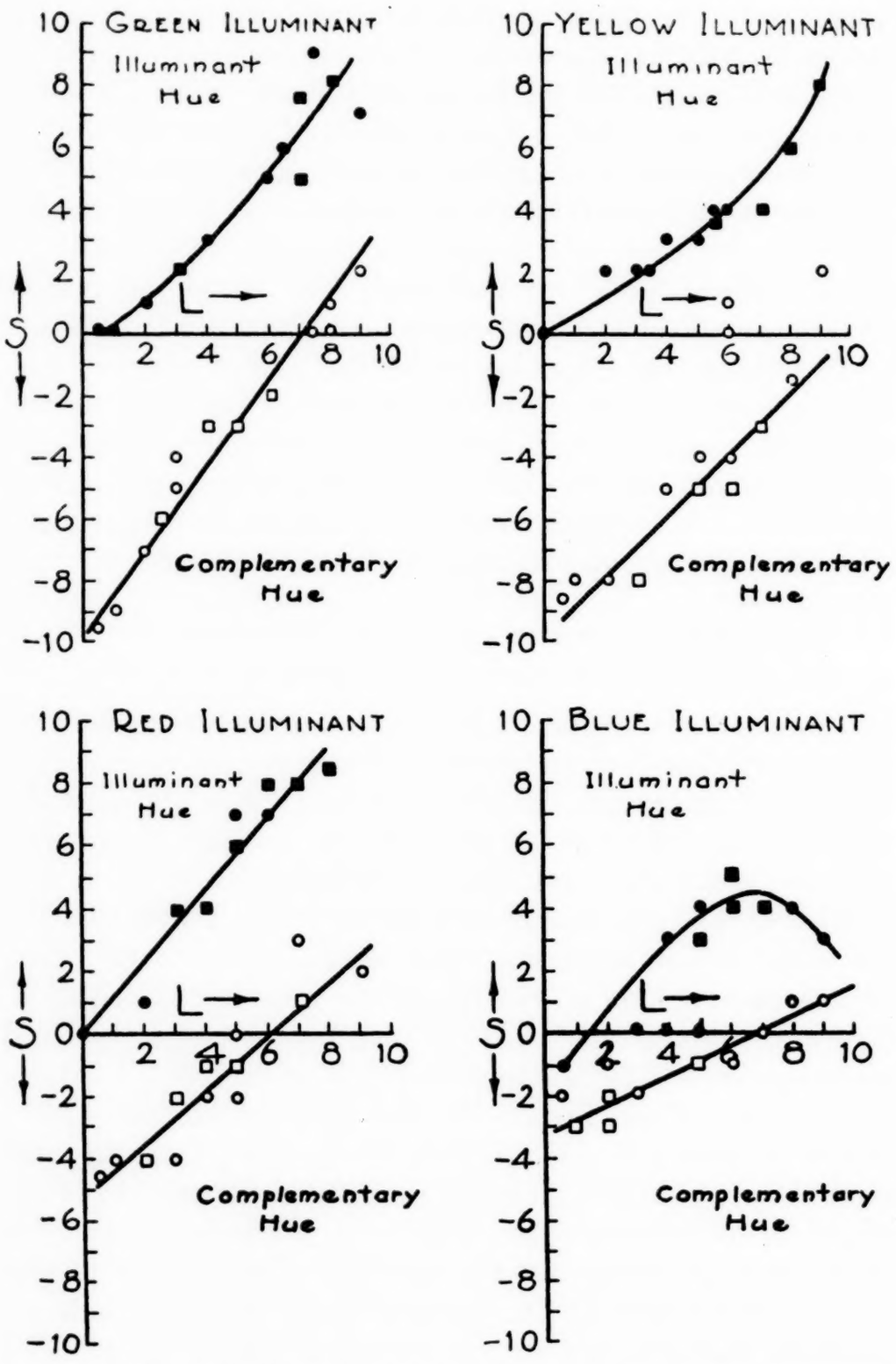

FIG. 2. Curves showing lightness-saturation relationships. Negative saturations refer to complementary hues. Solid circles and squares refer to 'black' background, outline to 'white' background. Points on the *x*-axis represent achromaticity. Squares indicate several identical reports.

view based on the implications of the color pyramid, maximum saturations occur with lightest or darkest samples, depending upon the background.

Differences in the exact relation between lightness and saturation are revealed in Fig. 2 for the different illuminations. The increase in saturation with increase in lightness for cases above the achromatic point appears to be linear for the green and yellow illuminants, with no falling off in saturation as the samples get lighter, as we should expect from the color pyramid. In the blue illuminant, however, maximum saturation is found at about medium lightness followed by a definite drop in saturation with higher lightnesses. The results for the red illuminant give curves falling between the green and yellow on the one hand and the blue on the other, the lightness-saturation curve for the red tending to flatten out (but not to drop) after medium lightness. Unfortunately the red curve of the S whose results are plotted in Figs. 2 and 3 do not show this characteristic as well as other Ss do. The curves on the 'gray' ground (Fig. 3) show no tendency to flatten or drop above the achromatic point because this ground does not lighten samples as much as the 'black' ground does. All curves for all illuminants show no tendency to flatten or inflect with decreasing lightnesses below the achromatic point so here we san say that the relationship between lightness and saturation is inverse and linear throughout.

The results with the various illuminants parallel the well-known fact that the most saturated blue surface colors are dark, whereas the best yellows are light. The similarity of behavior under the yellow and green illuminants may be due to the fact that the green illuminant had a strong yellow component as shown by reports on the light samples (Table 4). The tendency of the red curve to flatten with increasing lightness seems to indicate a truly intermediate type of behavior on the part of red as against yellow and blue; perhaps this type of behavior would be expected if the yellow and green curves could be experimentally extrapolated to higher lightnesses.

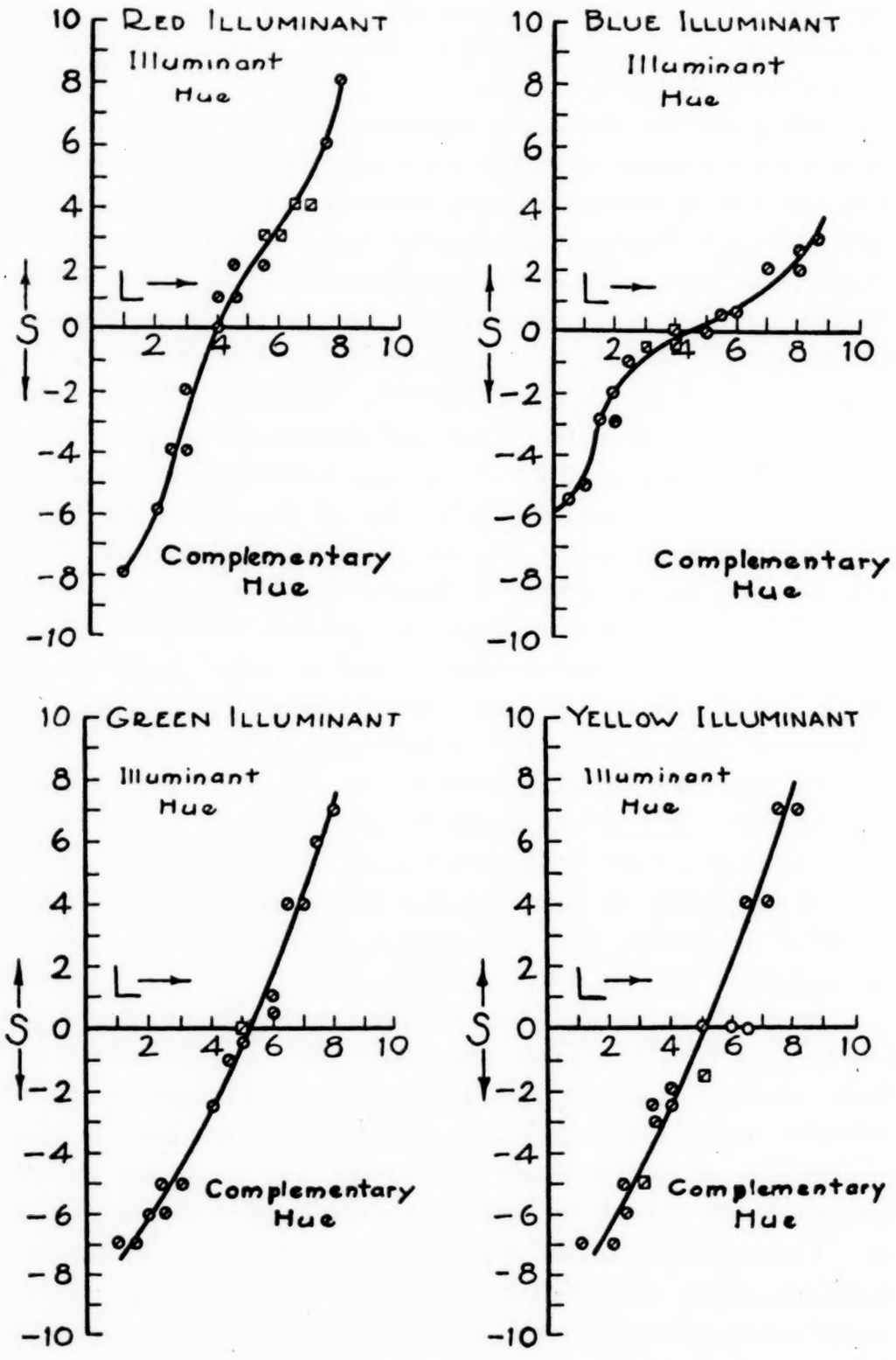

FIG. 3. Curves showing lightness-saturation relationships on 'gray' background Negative saturations refer to complementary hues. Squares indicate several identical reports.

The tendency of Ss to judge samples in groups is clearly evident in Figs. 2 and 3, wherein clustering of points appears frequently.[6] Grouping of samples occurs when color differences are small and difficult to judge. If the saturation-lightness functions are known for each illuminant, then we can predict the colors of the various samples and can point to the ones which have been wrongly reported by a hasty or otherwise incompetent S. At present we do not have enough evidence to assert that the relationships given in Figs. 2 and 3 are general for the illuminants in question. Results for selective samples on selective backgrounds in chromatic illumination give a more complicated picture. This question needs investigation under a greater variety of conditions—a task upon which we are now engaged.

Effect of Intensity Changes on Lightness and Saturation

While it has been known that there is considerable 'brightness constancy' the usual references to it do not convey any notion of the amount of constancy in a quantitative way. We are interested in the effect of known changes in illumination intensity on the lightness and saturation of colors. Table 6 contains reports on hue, saturation, and lightness of the three crucial samples among the 19 non-selective ones used in our experiments, *viz.*, the 'white,' 'gray' and 'black' samples. The results for only the extreme intensities having a ratio of 1 to 96 have been given in Table 6 since one of the medium intensities is reported in Table 4.

Inspection of Table 6 reveals that large changes in intensity of illumination have comparatively little effect on the hues, saturations, and lightnesses of the non-selective samples in chromatic illumination. We have found that mere change of background reflectance has greater effect on hue shifts and other attributes than changes in intensity of illumination. While a slight tendency is evident for lightness and saturation to drop about one step at the lowest intensity, the preservation

[6] Part of the clustering is no doubt due to the fact that some of the samples have practically identical reflectances and cannot be expected to have different colors.

of lightness values with change in intensity helps maintain hue and saturation constancy. Raising or lowering the illumination as such which affects both ground and samples

TABLE 6

SHOWING THE EFFECT OF CHANGES IN INTENSITY OF CHROMATIC ILLUMINATION ON NON-SELECTIVE SAMPLES ON DIFFERENT BACKGROUNDS

Sample	Red Illumination					
	7.0 f.c.			0.073 f.c.		
	Wh	Gr	Bl	Wh	Gr	Bl
A 10/0.....	R 9.0/3.0	RY 8.0/7.5	yR 7.5/7.0	RY 7.5/4.0	yR 7.5/8.0	yR 7.0/8.0
A 5/0.....	A 4.5/0.0	RY 5.0/1.0	yR 4.5/4.0	A 4.5/0.0	A 3.0/0.0	yR 4.0/3.5
A 0/0.....	BG 2.0/8.0	BG 2.0/5.0	A 0.0/0.0	bG 1.2/7.0	BG 1.0/1.5	A 0.0/0.0
	Yellow Illumination					
	49.0 f.c.			0.510 f.c.		
A 10/0.....	Y 9.0/7.0	Y 9.0/8.5	Y 8.5/8.0	Y 8.5/5.0	Y 8.0/7.0	Y 8.0/8.0
A 5/0.....	RB 5.0/1.5	Y 5.0/1.5	gY 5.5/3.5	A 4.5/0.0	A 4.5/0.0	YR 5.0/2.5
A 0/0.....	RB 1.5/7.0	rB 2.0/2.5	A 0.0/0.0	A 0.0/0.0	B 0.5/0.5	A 0.0/0.0
	Green Illumination					
	5.10 f.c.			0.058 f.c.		
A 10/0.....	yG 8.5/3.0	YG 9.0/6.0	yG 8.5/8.5	G 8.0/2.5	yG 8.0/6.0	yG 8.5/5.0
A 5/0.....	YG 5.0/1.0	A 5.0/0.0	yG 4.5/4.0	rB 4.5/2.0	yG 5.0/0.5	G 5.c/0.5
A 0/0.....	RB 1.0/6.0	RB 2.0/1.0	A 0.0/0.0	RB 1.0/4.5	RB 1.0/7.0	A 0.0/0.0
	Blue Illumination					
	0.82 f.c.			0.0085 f.c.		
A 10/0.....	B 8.5/3.0	B 9.0/5.0	B 8.5/5.0	B 8.0/3.0	B 7.0/6.0	B 7.0/5.5
A 5/0.....	RB 4.5/1.0	A 5.0/0.0	rB 5.0/4.5	A 4.5/0.0	A 5.0/0.0	rB 5.0/1.0
A 0/0.....	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0

equally leaves the lightness of the individual samples unaltered. It is interesting that dropping background from high to low reflectance or *vice versa* causes profound changes because the relation of sample reflectance to adaptation reflectance is changed. Changes affecting the whole field

but leaving the gradients (to use Koffka's term) unchanged have but little effect.

Paralleling the tolerance to large variations in intensity of illumination is the tolerance to variations in composition of illumination. This concerns the extent of constancy and conversion when composition of illumination is altered and to this subject we now turn.

Tolerance to Chromatic Illumination or Extent of Constancy

The question arises: "How much strongly chromatic light can be mixed with lamp [7] light before samples lose their lamp light colors?" Actually we proceeded from the opposite direction since we began with strongly chromatic illuminants and added incandescent-lamp light (light from the 2850° K. source). Under our initial conditions chances for constancy phenomena were very much reduced, although some samples retained their daylight colors. By adding lamp light until most of the samples were reported in their lamp light hues (which were identical with daylight reports) we were able to obtain a quantitative measure both of the amount of chromatic illumination which can be tolerated before objects lose their lamp light appearance and also the extent to which objects remain constant.

The data in Table 7 are based on a selection from the non-selective samples and include only the samples of highest, medium, and lowest reflectances. From Table 7 we see that the darkest sample on 'black' ground shows the greatest constancy since it is reported as achromatic in all cases. In fact 'black on black' shows the greatest constancy in all our experiments and we can understand why it does from our general principle. With the other samples we find that with as little as 0.0123 of lamp light in the mixture, samples begin to lose their chromatic appearance and when 0.0688 or 7

[7] In the interests of accuracy the term 'lamp' light will be used in this section instead of 'daylight' or 'white' light as we actually mixed light from the 2850° K. incandescent-lamp with the filtered light. However, only slightly different protocols would appear had 'daylight' been used.

percent lamp light is added to the chromatic illumination almost all the non-selective samples have returned to their lamp light (daylight) appearance, *i.e.*, are called achromatic again. It will be seen from Table 7 that samples on 'white' ground return to their lamp light appearance before those on 'black' ground which induces the illuminant hue on the samples.

TABLE 7

SHOWING THE EFFECT OF ADDING LAMP LIGHT (COLOR TEMPERATURE 2850° K.) TO CHROMATIC ILLUMINATION ON THE COLOR OF SAMPLES OF HIGH, MEDIUM, AND LOW REFLECTANCE ON THREE BACKGROUNDS

Sample	W Backgd.	G Backgd.	Blk. Bckgd.
Red Illumination Plus 0.0045 2850° K.			
A 10/0	R 9.0/0.5	R 8.0/3.0	R 7.0/7.5
A 5/0	gB 4.0/0.5	R 4.5/1.0	bR 5.0/6.0
A 0/0	BG 0.5/3.0	GB 1.0/2.0	A 0.0/0.0
Red Illumination Plus 0.0123 2850°K.			
A 10/0	yR 9.5/0.5	yR 9.0/1.0	yR 7.5/4.5
A 5/0	R 5.0/0.5	R 5.5/1.0	bR 5.0/4.5
A 0/0	bG 0.5/10	A 0.0/0.0	A 0.0/0.0
Red Illumination Plus 0.0688 2850° K.			
A 10/0	RY 9.5/0.5	R 9.5/0.5	R 9.0/1.0
A 5/0	A 4.5/0.0	A 5.5/0.0	bR 6.0/4.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0
Yellow Illumination Plus 0.0045 2850° K.			
A 10/0	Y 9.0/3.0	Y 8.0/7.0	Y 8.0/8.0
A 5/0	RB 5.0/0.5	Y 5.0/0.5	Y 5.0/4.0
A 0/0	rB 1.0/4.0	B 0.5/0.5	A 0.0/0.0
Yellow Illumination Plus 0.0123 2850° K.			
A 10/0	Y 9.5/2.0	Y 9.0/5.0	Y 8.0/7.5
A 5/0	rY 4.5/0.5	Y 5.0/0.5	Y 5.0/4.0
A 0/0	rB 0.5/3.0	rB 1.0/1.0	A 0.0/0.0
Yellow Illumination Plus 0.0688 2850° K.			
A 10/0	Y 9.5/0.5	Y 9.5/0.5	Y 9.0/4.0
A 5/0	A 5.0/0.0	A 5.0/0.0	gY 5.0/3.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0

TABLE 7 (*Cont'd*)

Green Illumination Plus 0.0045 2850° K.

Sample	W Backgd.	G Backgd.	Blk. Backgd.
A 10/0	YG 9.5/1.0	gY 8.0/3.0	gY 8.0/5.0
A 5/0	RB 5.0/1.0	A 5.0/0.0	yG 5.0/4.5
A 0/0	rB 1.0/2.0	RB 1.0/0.5	A 0.0/0.0
Green Illumination Plus 0.0123 2850° K.			
A 10/0	gY 9.5/0.5	gY 9.0/2.0	gY 9.0/4.0
A 5/0	A 4.5/0.0	GY 5.0/0.5	yG 5.0/3.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0
Green Illumination Plus 0.0688 2850° K.			
A 10/0	A 10/0.0	A 10.0/0.0	YG 9.5/1.0
A 5/0	A 5.0/0.0	A 5.0/0.0	yG 5.5/0.5
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0
Blue Illumination Plus 0.0045 2850° K.			
A 10/0	A 10.0/0.0	rB 9.5/0.5	RB 8.0/4.0
A 5/0	A 5.0/0.0	A 5.0/0.0	rB 5.0/5.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0
Blue Illumination Plus 0.0123 2850° K.			
A 10/0	RB 9.5/0.5	A 10.0/0.0	RB 9.5/1.0
A 5/0	A 4.5/0.0	B 5.0/0.5	RB 5.5/5.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0
Blue Illumination Plus 0.0688 2850° K.			
A 10/0	RB 9.8/0.2	A 10.0/0.0	RB 9.5/1.0
A 5/0	A 5.0/0.0	A 5.0/0.0	RB 5.5/3.0
A 0/0	A 0.0/0.0	A 0.0/0.0	A 0.0/0.0

Looking at the facts which we have just presented from the point of view of constancy we can say that non-selective samples remain achromatic when as much as 93 percent chromatic light is added to incandescent-lamp light. This fact accounts for the statement so often found in the literature that adaptation to colored glasses is so complete that objects appear in their 'normal' colors after a period of time. This statement is true, as Helson and Judd (**10**) have shown, only for glasses which are not rigidly selective in their transmissions. If only a small amount of spectrally heterogeneous

radiation is transmitted, objects will appear in their 'normal' colors. From the findings given in Table 7 when the intensity of the heterogeneous components is only 7 percent of the mixture, objects regain their daylight appearance. Constancy seems to be even more marked for selective samples, contrary to the often-expressed opinion that "brightness constancy is greater than color constancy." In the work with selective samples, to be reported later, we have found that with *as little as four-tenths of one percent non-homogeneous light, most of the samples are recognized even though the lamp light color may be contaminated by either the illuminant color or its complementary color as a minor component.* The greater constancy of selective samples in chromatic illumination is easily understood in terms of the reflecting properties which they possess as contrasted with those of the non-selective samples.

Our data furnish the first quantitative evidence of the extra-ordinary range of constancy effects. The remarkable adaptive and adjustive powers of the visual mechanisms have not only theoretical importance but practical as well.[8] The latter cannot be discussed here but to some of the theoretical questions we now turn.

What Remains Constant in Chromatic Illumination?

This question has received various answers ranging from the assertion that all non-selective samples remain achromatic in homogeneous illumination to the assertion that constancy is nil for selective samples in chromatic illumination (Bühler, **4**; Kardos, **23**; Krauss, **31**). Both views are invalid as generalizations apart from special conditions under which they have some truth. Non-selective samples near the achromatic point remain achromatic in homogeneous illumination, others do not. Selective samples whose daylight color is similar to the illuminant color or complementary to it, if

[8] Among the practical implications of our findings on the tolerance to chromatic illumination may be mentioned its importance for the glass industry, theater lighting, specifications of sources of illumination and transmissions of filters used as glasses for reducing glare or intensity of light reaching the eyes.

the latter are of low reflectance, retain their color more or less in chromatic illumination. On the other hand, non-selective samples may be chromatic and selective samples may be achromatic in chromatic illumination. Thus Kaila's generalization (**22**) that the changes in color in 'abnormal' illumination are toward the 'object color' holds only for special reflectances, provided 'object color' means daylight color of the object.[9]

We have seen from the observations reported in Table 4 that what will remain achromatic when non-selective samples only are used depends on the adaptation level and this, in turn, depends chiefly upon the background. By appropriate choice of backgrounds we can shift a sample from achromaticity to illuminant or complementary color. Some possibilities are ruled out, however. Thus we cannot make the sample of lowest reflectance take on the illuminant color, nor can we make the sample of highest reflectance take on the complementary color. The secret of generalization for 'achromatic' samples lies in the relation of sample to adaptation reflectance and our reason for stressing this fact springs from its complete neglect by previous workers.

The application of our principle to predictions of changes in selective samples in various illuminants involves nothing fundamentally new yet the fact of *selective reflectance* makes its discussion more complicated and this we leave to a later paper.

Color Conversion and the Film-Surface Dichotomy

It cannot be denied that important differences exist between the aperture and surface modes of color appearance

[9] The concepts of 'regression to real characters' proposed by Thouless (**36**) and of 'intended object' proposed by Brunswik (**3**) seem to be more applicable to constancy of form than to color constancy because it is impossible to assert that 'daylight' colors are more real than any other color which an object may have. By neither of these concepts can we predict how the color of objects will change with change in illumination, background, *etc.*, since the S neither 'intends' nor knows what the 'real' color of the object is under strongly chromatic illumination. The assumption of some psychologists and colorimetrists that the aperture color is the 'real' color of the object is equally untenable and has retarded the progress of visual science and should be given up.

and the contributions of Katz (**26**) to our knowledge of these and the other modes constitute the outstanding contribution to the psychology of color in this century. The assumption has been made very frequently, though implicitly, that in the aperture mode we 'see' what is given on the retina while in the other modes perceptual, memorial, or other 'higher' psychological processes are involved. While largely given up by psychologists there are still some who cling to 'real' *vs.* imaginal or perceptual attributes of colors and so we must show that the functional differences between the aperture and surface modes do not justify any such dichotomy even though descriptive differences do characterize the various modes.

First, contrary to the usual assumption according to which aperture colors have only the color of the illuminant, we find that they are subject to the operation of our principle. Thus if we illuminate the side of the reduction screen facing the S with strongly red illumination and gradually then reduce the intensity of the red illumination behind it, the aperture color changes from red to achromatic to blue-green. The effect on an aperture color of illuminating the screen with chromatic light is, of course, always toward the complementary color because the aperture does not act as a reflector. Only if the reduction screen is of very low reflectance and free from illumination can we be sure that the aperture color will not be affected, as others have also found (Kardos, **22**). This fact does not invalidate the reduction screen as a device for making matches between colors provided that the surroundings of both aperture colors are identical. The question has arisen as to whether the identity should be merely apparent or physical as well. Experimental results are conflicting as some writers maintain that contrast effects are determined by the phenomenal gradients (Gelb, **6**) while others (Katz, **26**, Kravkov and Paulsen-Baschmakowa, **34**) assert that the reduced or physical relations determine contrast. In all of the experiments reported the eyes were not exposed to unitary illumination conditions and so it is useless to expect univocal results or valid generalizations. When the eye is

subjected to a single illumination, when differences in the field are subordinated to the general illumination, and when reduction screens are illuminated in the same way then we find no differences between surface and film colors so far as the effects of surroundings are concerned.

Secondly, the assumption that contrast is peripheral and constancy is central (Katz, **26**, G. E. Müller, **39**) or that there is both a peripheral and a central contrast (Haack, **9**) must be given up with the assumption that aperture colors are peripheral and other modes are central. Much of the difficulty in judging 'transformed' colors disappears when unitary illuminations are used and conditions are made sufficiently compelling, as has been noted by Marzynski (**38**); Gelb (**7**, **8**); Kravkov (**33**, **34**, **35**); and Katona (**25**). With the recognition of the fact that individual differences are no greater for transformed than for aperture colors and with the demonstration that aperture colors are subject to our principle as well as surface colors, the props for the assumption of different loci for these phenomena are taken away. Only when no light is falling on the reduction screen can one be sure that aperture color is free from contrast and transformation effects. We have found no reason either in our own work or in the reports of experiments in the literature to admit that our single principle does not cover all cases. All the evidence, when properly interpreted, points to a unitary mechanism underlying all the phenomena.

Conversion, Contrast, Adaptation, and Constancy

The failure to recognize that a single principle operates in every act of vision has been responsible for the many conflicting views regarding the relation of contrast to constancy, of adaptation to constancy, and of constancy to conversion, *etc.* Our principle makes but the one assumption, fully borne out by the facts, *viz.*, in every act of vision provided the eye is subjected to a unitary illumination there is established an adaptation reflectance or achromatic point such that there exists at least one sample whose reflectance is such that it

will be seen as achromatic. This adaptation reflectance is determined chiefly by the background reflectance but is influenced by reflectances of the samples in the field, particularly in the case of backgrounds of high reflectance, when it is found to be lower than the background reflectance. The hue, saturation, and lightness of the samples in the viewing field then become functions of the relation of sample to background reflectance in the manner pointed out above. This principle holds also for non-selective samples in heterogeneous illuminations as well as to selective samples in homogeneous illuminations.[10]

It is evident that the classic views of contrast and adaptation as well as more recent theories of constancy and contrast cannot be made to yield what is contained in our formulation. On the other hand, our principle comes into conflict with the classic views at certain points where the latter fail to explain the facts correctly. Thus the classic view that contrast effects are greatest when brightness differences are least cannot explain our fact that the greater the difference between ground and sample brightness the more saturated will be the contrasting hue of the latter. We are able to explain certain facts of contrast without the assumption of a 'brightness' contrast in addition to the chromatic contrast of the classical view which leaves out the effect of the illumination on the samples. The desaturation of contrasting colors when the contrasting fields are widely different in brightness we explain as due to the induction of the white of the illuminant or its complementary black, because in most cases the observations are made in fairly *white* light. Not only does our explanation simplify the theory of contrast but it serves to relate contrast to constancy and conversion by bringing in the illumination.

Some writers who have seen the shortcomings of the classic view of adaptation have tried to dispense with its effects altogether in explaining constancy (for example, Katz, **26**), while others have attempted to make adaptation do more

[10] While the members of the Vienna school have stressed the importance of reflectance (albedo) for non-selective samples they have not seen that it is of equal, if not greater, importance for selective samples.

than it usually does, *e.g.*, Koffka when he writes: "in monochromatic illumination all objects should appear neutral inasmuch as according to our principle of the neutral level the whole visual field should look neutral and therefore differences in intensity appear as differences in the black-white and the dark-light dimension" (**28**, p. 257–258). We have seen that adaptation usually does not render backgrounds and samples of high reflectance achromatic in homogeneous illumination and the appearance of the complementary hue with samples of low reflectance makes Koffka's principle doubly invalid. *The effect of adaptation is to establish a region or point of achromaticity beyond which, in homogeneous light, the illuminant and its complementary hues appear.* Adaptation cannot reduce surfaces of high reflectance to achromaticity. Adaptation, as Katz has rightly seen, cannot account completely for all cases of constancy, but it can establish, as Koffka has rightly seen, a level or point with respect to which the phenomena are to be explained.

Our use of strongly chromatic illumination, at first apparently 'unnatural' and restrictive, proves the best means for demonstrating the existence of an adaptation reflectance and its dependence on 'average' reflectance with its resulting effect on constancy and conversion. Chromatic illumination thus furnishes the key to the essential unity of all the phenomena of vision.

Individual Differences in Color Conversion

Individual differences in transformation and color perception under 'abnormal' illumination have been stressed in the literature and used as an argument for the central origin of some of the phenomena which seemed to obey no law. While we have found differences in report among our Ss they do not substantiate the view that phenomena of constancy, conversion and contrast are mediated by different parts of the visual mechanism or in different regions of the nervous system. There are several sources responsible for individual differences in report under conditions of 'abnormal' illumination, most of them capable of control and largely eliminable

with practise and control of conditions. Yet though there are real differences in color vision which cannot be regarded as artifacts they cannot be used in favor of central or peripheral theories of the various phenomena we have been discussing.

First among the genuine individual differences which we have found is the position of the achromatic point.[11] With a given background some Ss report sample 15 (Table 4) achromatic while others report 17; some Ss report a single sample achromatic, others a whole range of samples under identical viewing conditions. One of the reasons for the latter type of report is to be found in the tendency of some Ss not to report small amounts of chroma. This may be due to lesser sensitivity or to less care in observation and report, more frequently the latter because when Ss are warned to report 'everything you see' fewer achromatic reports are given. The position and range of achromaticities for any S are important since they determine the reports of illumination and complementary colors.

Genuine differences in sensitivity seem to exist with respect to the emergence of the various components in the after-image. Thus in red illumination one S reports no intermediate RB in passing from A to bG whereas all other Ss report an R component before passing either to gB or to BG (*Cf.* Table 4). To take another example, where some Ss report R others report RY or, if the range of achromaticity is great, others will report as A samples which the former Ss have given as R or RY. Greatest differences are found where the judgments are hardest, *i.e.*, near the adaptation reflectance for here the samples tend to lose in saturation and difficulty is experienced in reporting slight saturations. Furthermore, there is a good deal of fluctuation in hue as the eyes move over the sample plane especially if S fixates steadily for even several seconds.

Certain agreements in difference appear: under the red illumination, four Ss give reports showing a decidedly blue

[11] Pierce (**40**) has pointed out that differences in retinal pigmentation can lead to differences in judging and matching colored stimuli. Variations in density and dominant hue of the macular pigment may shift the "white point" of normal trichromats (**40**, p. 34).

inducing effect on the samples from 'white' ground while these same Ss show a red inducing effect with the blue illuminant (see Table 4 as the results of the S reported there show this tendency). With the yellow illumination one S (the S given in Table 4) shows an R component in the dark samples on W and B grounds while five other Ss show this tendency only on the W ground. Excellent agreement was found with the green illuminant and the B and G grounds but with the W ground three Ss called the lightest samples YG or yG while three others called these samples A.

Judgments of lightness show some variation with respect to 'level.' Some Ss raise all the values on the 'black' as contrasted with the 'white' ground while others do not. Some Ss tend to call the lightest sample in the field 10, the maximum allowed, and to judge the others accordingly, while other Ss ascribe lower values to the lightest samples. Similarly, values for saturation may be raised or lowered as a whole and the highest saturations may be given the maximum permitted or something less, depending upon the individual S. But none of the individual differences we have found justify the separation of contrast from constancy mechanisms as Katz (**24**), G. E. Müller (**34**) and others have sought to do. By appropriate choice of conditions we have found a single principle applies to all the phenomena and this points to a single underlying mechanism.

Summary

Non-selective samples in chromatic illumination have been shown to exhibit the color of the illuminant, the color of the after-image complementary to the illuminant, or achromaticity, depending upon the relation of the reflectance of the sample to the adaptation reflectance. Change of background has been found sufficient to shift the color of a sample from the illuminant color to achromaticity or to the complementary color. The neglect of the effect of background in previous studies invalidates the theories proposed for phenomena obviously springing from this source. Constancy is found either when the illuminant is not sufficiently homogeneous for

conversion or when sample and adaptation reflectances happen to coincide. Quantitative determinations of the extent of constancy and the beginnings of conversion are reported for the first time.

Theories which assign more or less independence to object as against illuminant color, which separate constancy, contrast, adaptation, and conversion, and which ascribe different behavior with respect to these mechanisms to film and surface modes of viewing are shown to be based upon one-sided conditions under which the observations were made supporting them. A single principle has been found adequate to explain and predict how object colors change with change in illumination and background. The fact that one principle suffices for illuminant, contrasting, or preservation of daylight color argues for a single mechanism underneath the varied phenomena of color vision in all conditions.

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EXPERIMENTS ON MOTOR CONFLICT. I. TYPES OF CONFLICT AND THEIR MODES OF RESOLUTION *

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Introduction

Lewin [1] has employed his concepts of vectors and field forces in distinguishing three types of motivational conflicts. In his *Type I* conflicts the organism is simultaneously attracted to two objects with positive valences (*e.g.*, the child is torn between a chocolate candy and a kitten which he wants to stroke). This type may be called an *approach-approach* conflict. In *Type II* the organism is simultaneously *attracted* toward an object with positive valence and *repelled* from one with negative valence when both objects occupy the same spatial position (*e.g.*, "a three-year-old boy wants to fetch a rubber swan out of the water to the beach, but is afraid of the water" (p. 92)). This variety will be referred to as an *approach-avoidance* conflict. *Type III* is a conflict between incompatible avoidance reactions to two objects with negative valences (*e.g.*, "it is sought by threat of punishment to move a child to do a task he does not want to do" (p. 91)). This is labelled an *avoidance-avoidance* conflict. A fourth type, perhaps more nearly approximating real life conflicts than these three, may be educed—that in which the organism faces two interlocking Type II situations at once (*e.g.*, a man has two desirable appointments at the same hour, the neglect of either of which will produce punishment or disappointment).

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[1] Lewin, K. *A Dynamic Theory of Personality.* New York: McGraw-Hill, 1935. All succeeding references to Lewin refer to this volume.

From his postulates Lewin deduces (pp. 88–96) that the resolutions of his three types of conflict will be markedly different. Type I should produce little blocking and the organism should approach one or the other of the objects with positive valences. Conflicts of Type II and Type III should lead, in general, to resolution by withdrawal from the field of forces, although the specific behavior to be observed will depend on a number of collateral factors.

Because of the difficulty of getting these motivational and emotional conflicts uncomplicated by other factors, it seemed desirable to investigate conflicts at the motor level where precise control of the experimental situation and accurate measurement of the resolutions are possible. It is hoped that uncovering of the major variables at this level will permit greater efficiency in later investigations of more complex conflict phenomena. The motor conflict was obtained by having a subject practice, in random order, two incompatible manual responses and then presenting simultaneously the two lights which had served as signals for the two individual responses.

Method

Apparatus.—The manual responses between which conflicts were developed are most easily described in connection with the apparatus (Fig. 1). The subject sat at a table on which was a smooth metal plate, 6 × 6 inches, which was bordered by brass strips 1 inch wide and 1/4 inch thick (*B*). The two side strips were raised 1/4 inch so that 6-inch-wide stylograph paper (*P*) would slide through and serve as a wax surface 6 inches square on which the subject could mark. At the middle of the side toward the subject a small nick (*N*) was cut in the inner edge of the brass strip. The subject rested his pencil in this at the beginning of each trial. For study of Types I and III conflicts an uncolored flash-light bulb in porcelain socket was mounted on the brass strip at each of the two corners away from the subject (*L*). Across the table from the subject, behind a large screen, the experimenter sat before a set of switches which permitted him to flash either of the lights alone or both together. For study of Type II conflicts the single socket at each corner was replaced by a pair of sockets arranged diagonally so that each member of the pair was approximately equi-distant from the nick in which the pencil rested. A red and a green flash-light bulb were placed on one corner. For Type IV conflicts red and green pairs of lights were placed at both corners. Switches were wired so that, in addition to a single light, both lights on one side or all four could be flashed simultaneously.

Instructions and Procedure.—The subjects were divided into four groups, one for each type of conflict.

Group I.—The subject was instructed to rest the point of his pencil on the wax paper in the nick and respond as quickly as possible to the flash of a light by drawing a diagonal line directly from the nick to the corner at which the light flashed. After 10 reactions toward each light, in random order, both lights were flashed simultaneously as the 21st trial (approach-approach conflict).

Group II.—A red and green light were placed at one corner of the board only and the subject was instructed to go *toward* the flash of one (*e.g.*, green) and *away* (opposite corner) from the flash of the other. On the 21st trial the two lights were flashed simultaneously (approach-avoidance conflict). Three variables were involved in this situation which did not occur with Types I and III: (1) Side—the corner of the board, right or left, on which both stimuli were placed, (2) Position—the position of the 2

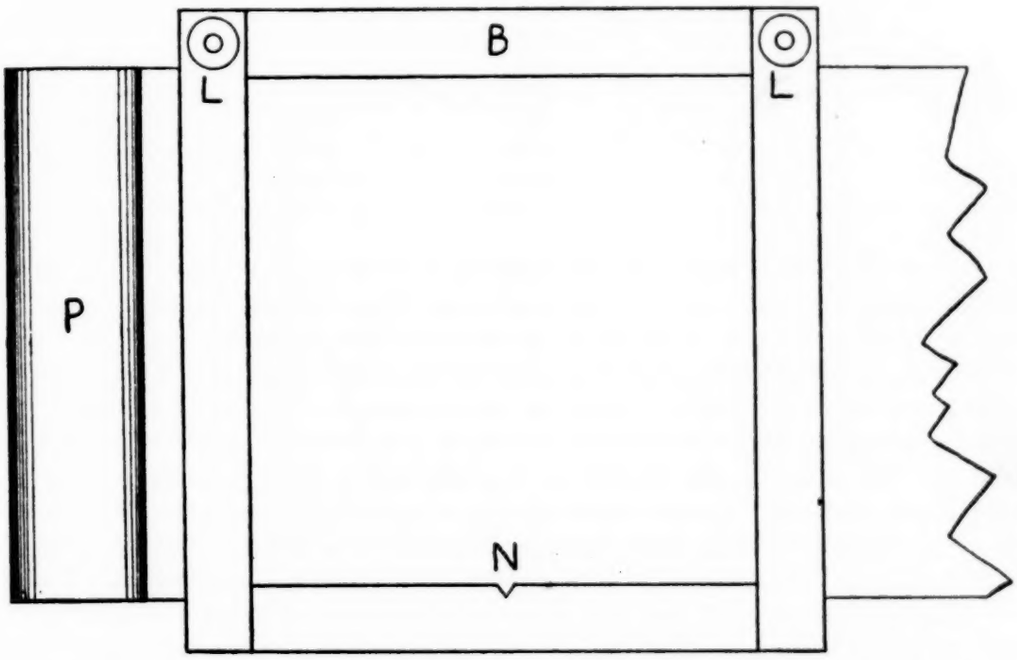

FIG. 1. Diagram of the conflict board. (P = roll of stylograph paper; B = brass border; N = nick in which stylus rests and from which reactions start; L = lights.)

bulbs relative to one another, whether outside or inside, and (3) Instructions—the character of the instructions, whether to approach or to avoid, in relation to the color of the light. In order to determine whether any of these 3 variables would influence the kind of resolution made to the Type II conflict the group was divided into 8 sub-groups of 20 subjects each; these 8 sub-groups permitted the presentation of each variable in each of its 2 degrees of freedom with each of the other two variables occurring in each of their 2 degrees of freedom. Table 1 indicates the various combinations required for adequate control. In the first sub-group, for example, the lights were at the left corner of the board, the red bulb being the *outside* member of the pair, and the instructions were to go toward the green bulb and *away* from the red. Exactly opposite conditions obtain in the sixth sub-group.

Group III.—This group was treated essentially the same as Group I except that the subject was told to go to the *opposite* corner (away from light) in response to the flash (avoidance-avoidance conflict).

TABLE 1

THE 8 SUB-GROUPS NECESSARY FOR CONTROLLING THE 3 EXTRA VARIABLES IN TYPE II CONFLICTS

Side = side of board on which lights were placed. Position = position of *red* bulb, whether in inner or outer socket. Instructions = instructions to subject, whether to go toward or away from red light.

Sub-group	*N*	Variables		
		Side	Position	Instruction
1	20	left	out	away
2	20	left	in	toward
3	20	left	out	toward
4	20	left	in	away
5	20	right	out	away
6	20	right	in	toward
7	20	right	out	toward
8	20	right	in	away

Group IV.—Pairs of red and green bulbs were placed at both corners of the board and the subject was instructed always to go *toward* the green light and *away* (opposite corner) from the red light, no matter on which side a light appeared. Since this situation involved differential reactions to 4 lights instead of only 2, more trials to each light were given before the conflict stimulation was presented. Instead of 20 simple responses there were 80 and the conflict stimulation was presented as trial 81 instead of trial 21. The subjects were divided in 2 sub-groups; *a*, those to whom a Type II conflict was presented by simultaneous lighting of the red and green bulbs on only one side, half the subjects being presented with the left pair and half with the right pair; *b*, those to whom a Type IV conflict was presented by simultaneous flashing of all 4 lights.

The light flashes in all cases were presented by manual switches, the duration of each stimulus for the practice trials being approximately 1 second. Duration of stimulation on the conflict trials was slightly longer.

Subjects.—*Groups I* and *III* were each composed of 80 Yale students who were paid for their services; the majority of them, from elementary and social psychology classes, volunteered to serve at a nominal fee. *Group II* was composed of 74 Yale students who were paid for their services, and 86 members of a Y. M. C. A. boys' camp, aged 13 to 19, who served voluntarily. *Group IV* was composed of 66 Yale students who were paid for their services. In no case was any subject used in more than one group.

RESULTS

The experimental situation was designed to force as much as possible a resolution of the conflict at the manual level and within the field of conflict. It was impossible to prevent verbal or imaginal resolutions completely (*e.g.*, laughter, giggling, swearing, shifting of attention from board to experimenter) but in so far as manual responses occurred, the nature of the

board prevented physical withdrawal from the field in every case.

Modes of Resolutions.—Analysis of records suggested that there were 4 easily identifiable kinds of reaction to conflicts, 3 of which can clearly be called resolutions; the fourth, com-

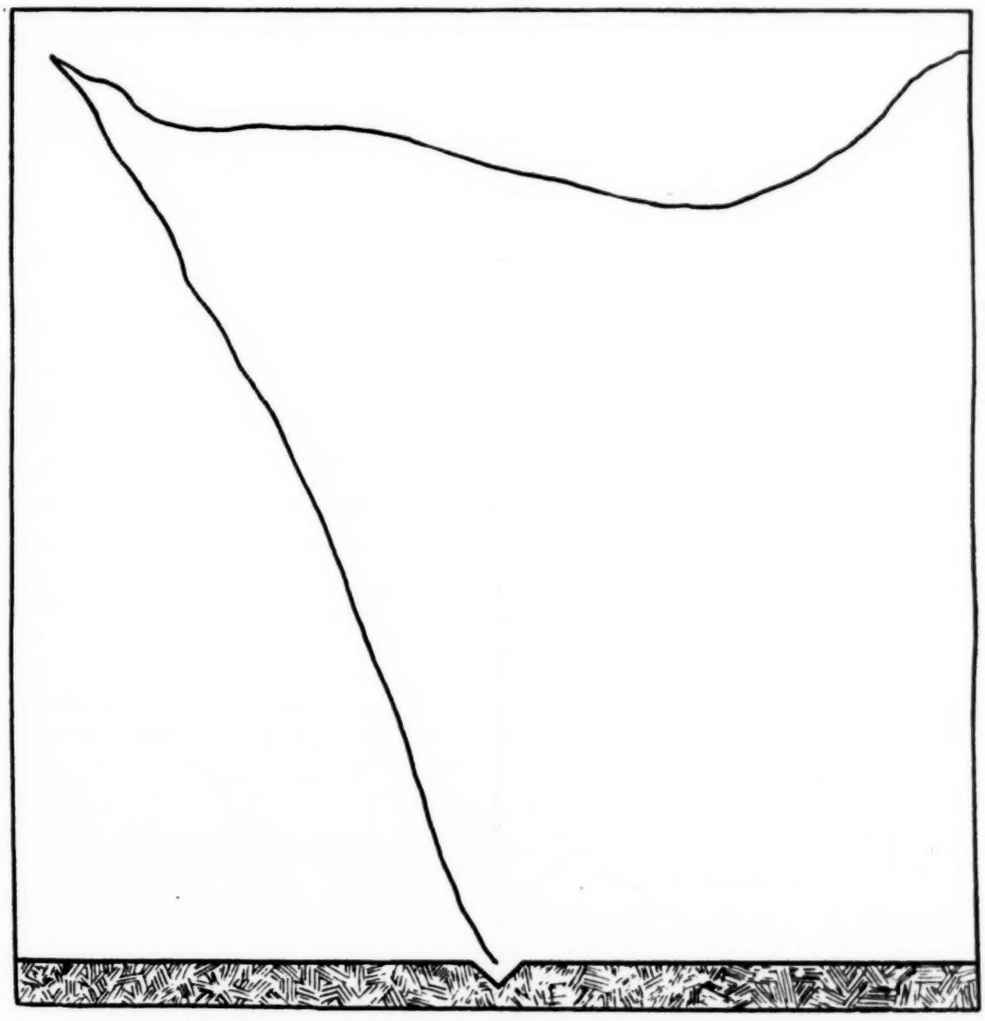

FIG. 2. One form of the *Double* mode of resolution.

plete blocking, is probably an accompaniment of some unmeasured and non-manual resolution. These 4 reactions were as follows:

1. *S—single* response only; *i.e.*, drawing a line directly to one of the two lights.

2. *D—double* reaction; *i.e.*, response to both signals. In nearly all cases this involved going to the corner designated by one signal, returning quickly to the nick and then going

to the opposite corner. In a few cases the first movement was followed by drawing a line directly across the top of the board to the opposite corner (Fig. 2).

3. *C—compromise* movements by going up the center of the board half way between the 2 corners (Fig. 3).

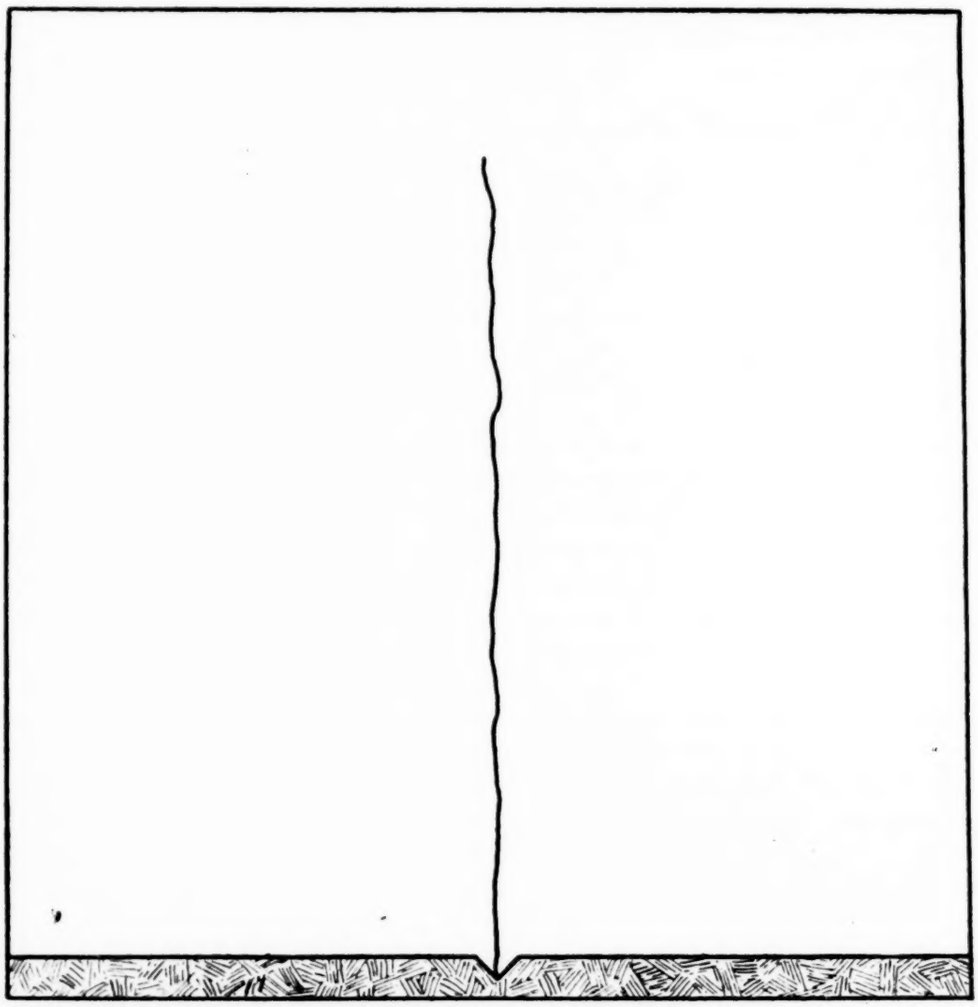

FIG. 3. *Compromise* mode of resolution.

4. *B—blocking;* no manual response whatever. Presumably every conflict must eventually be resolved; blocking may represent an unusually long reaction time.

A quantitative comparison of the modes of resolutions characteristically made to the first three types of conflict situations is presented in Table 2. The contrast between the resolutions to Types I and III conflicts is immediately apparent. With the former type only 8.75 percent of the

TABLE 2

THE PROPORTION AND S.D. OF THE PROPORTION OF CASES, IN PERCENTAGE, RESPONDING WITH EACH OF 4 MODES OF RESOLUTION TO EACH OF 3 TYPES OF CONFLICT

Conflict Type	*N*	Mode of Resolution							
		S		*D*		*C*		*B*	
		%	S.D. %	%	S.D. %	%	S.D. %	%	S.D. %
I.....	80	57.50	5.6	21.25	4.6	12.50	3.8	8.75	3.2
II.....	160	14.37	2.8	46.88	4.0	10.63	2.5	28.12	3.6
III.....	80	17.50	4.3	7.50	3.0	28.75	5.1	46.25	5.6

subjects blocked and only 12.5 percent carried out a compromise movement. Subjects confronted with a Type III conflict blocked in 46.25 percent of the cases, however, and 28.75 percent of them made compromise movements.[2] If the *B* and *C* modes of resolution are summed,[3] Type I has only 21.25 percent (S.D. = 4.6 percent) of these resolutions, while Type III has 75.0 percent (S.D. = 4.9 percent). Type II

TABLE 2*a*

THE PROPORTION OF CASES, IN PERCENTAGE, RESPONDING WITH EACH OF 4 MODES OF RESOLUTION TO TYPE IV CONFLICTS (80 PRELIMINARY PRACTICE TRIALS) AND TYPE II CONFLICTS WITH COMPARABLE PRACTICE CONDITIONS

Conflict Type	*N*	Mode of Resolution			
		S	*D*	*C*	*B*
II.....	22	31.8	13.6	0	54.5
IV.....	40	10.0	12.5	5.0	72.5

conflicts are more typically resolved by double responses and present a quite different picture from either I or III.

The salient characteristic of resolutions to Type IV is found to be the tremendous proportion of blocked responses.

[2] A repetition of this experiment, with an apparatus in which the incompatible responses were made to 2 lights directly opposite each other instead of at opposite upper corners of a V, has yielded similar values but with a reduction of Compromise resolutions and an equivalent increase in Blockages.

[3] Evidence will be given below that there is justification for this summing.

But the data on Type IV conflicts are not strictly comparable to those for the first 3 types because there were 80 training trials instead of the customary 20 (Types I, II, III). The data are therefore presented separately (Table 2*a*). To determine the effect of the increased training, Group IV*a* was presented with Type II conflicts after training which was identical with that of Group IV*b* (Type IV conflicts). The proportion of blockages was not quite as large with the former as with the latter but it was still twice as great as the proportion of blockages in Group II (simple Type II conflicts; Table 2). There are two factors which may have contributed to

TABLE 3

PERCENTAGE OF SUBJECTS EMPLOYING EACH MODE OF RESOLUTION WITH TYPE II CONFLICTS

Sub-groups are described in Table 1.

Sub-group	*N*	Style of Resolution			
		S	*D*	*C*	*B*
1	20	15	30	0	55
2	20	10	40	15	35
3	20	30	50	5	15
4	20	10	65	10	15
5	20	5	40	20	35
6	20	10	45	25	20
7	20	20	50	10	20
8	20	15	50	5	30

this difference: one, the greater complexity of the discrimination task practiced by the subjects of Group IV*a*, and the other, the greater amount of practice on the two responses which were in conflict. A systematic investigation of this latter factor will be presented in a later paper.

Control of the Extra Variables in Group II.—In Table 3 are given the proportions of cases presenting each of the 4 styles of resolution under each of the 8 conditions of the balanced control sub-groups described in Table 1. Each sub-group contains 20 S's. In Table 4 are shown the proportions of each style occurring when the 3 factors are varied one at a time. For example, sub-groups 1 to 4 had the lights on the *left* side of the board while sub-groups 5 to 8 had them on the *right*.

TABLE 4

PROPORTION OF EACH OF THE 4 MODES OF RESOLUTION OCCURRING WITH EACH OF THE 3 VARIABLES HELD CONSTANT. DATA FROM TABLE 3

Variable	*N*	*S*	*D*	*C*	*B*
Side					
Left	80	16.25	46.25	7.5	30.00
Right	80	12.50	46.25	15.0	26.25
Position					
Out	80	17.50	42.50	8.75	31.25
In	80	11.25	50.00	13.75	25.00
Instruction					
Away	80	11.25	46.25	8.75	33.75
Toward	80	17.50	46.25	13.75	22.50

Comparison of the first 2 lines of Table 4 indicates that this factor (*Side*) had little or no influence in determining the proportion of cases in which each mode of resolution occurred. The other 2 variables also seem to have been relatively inoperative. The largest difference, that between the proportion of *B* resolutions when *Instructions* were to go *toward* or *away* from the red light, is only 1.5 times its S.E. The values for Group II in Table 2 represent the total group of 160 subjects with each of the 3 variables given equal weight.

A later paper will present evidence that age differences in Group II were related to the mode of resolution of Type II conflicts, but since the different aged subjects were equally distributed in the 8 sub-groups this factor can be ignored here.

Consistency of Response to Expected and Unexpected Repetitions of the Type II Conflicts.—Two further problems may be raised in connection with the present method of approach to the study of conflicts. The first concerns the consistency of an individual's methods of resolving a given type of conflict. Such concepts as hysterical or neurasthenic personality presume to some degree that individuals have consistent ways of behaving in conflict situations and that there are individual differences in these ways; these consistencies and differences are largely attributed to the individual himself rather than to the kind of situation with which he is confronted (*cf.* Janet). The second problem relates to the effect of knowledge *about*

the conflict situation, since it has been frequently supposed that such knowledge influences the mode of resolution. In order to throw some light on these problems, the 160 subjects presented with Type II conflicts were subjected to 4 repetitions of the conflict situation interspersed with 40 further practice trials, 10 practice trials being given between successive conflicts. To 80 of the subjects no information about the repetitions was given (Group A); they were carefully

TABLE 5

NUMBER AND KINDS OF SHIFTS IN MODE OF RESOLUTION DURING A SEQUENCE OF 5 CONFLICT TRIALS

Data are from the 19 S's in Group A (N = 80) and 22 S's in Group B (N = 80) who made one or more shifts during the series. Column 1 presents the shifts from first to second trial (1 → 2).

Group	Sequence of Trials									
	1 → 2		2 → 3		3 → 4		4 → 5		Total	
	A	B	A	B	A	B	A	B	A	B
No. of shifts	10	19	7	8	7	0	6	3	30	30
No. of intra-class shifts	5	10	6	2	7	0	5	2	23	14
No. of inter-class shifts	5	9	1	6	0	0	1	1	7	16
No. of Single-Double, etc.	5	8	6	0	6	0	5	2	22	10
No. of Block and Compromise Shifts	0	2	0	2	1	0	0	0	1	4

instructed to ask no questions after the experiment started. The other 80 subjects were instructed similarly but were told after the first conflict that the conflict situation would occur 4 more times during the experiment (Group B); at that time they were again told to ask no questions. Therefore, while the first conflict was comparable for all 160 subjects the group was divided into 2 sub-groups having different degrees of expectation concerning the occurrence of the 4 repetitions of the conflict.

Consistency of Mode of Resolution.—In Table 5 are shown for both groups the number and kinds of shifts in mode of resolution which occurred from one conflict to another during

the sequence of conflict trials. Of the 80 subjects for whom the repetitions were comparatively unexpected (Group A), 19 (24 percent) shifted their mode of resolution one or more times each. There was a total of 30 shifts during the series. For the whole group of 80 S's these 30 shifts represented only 9 percent of the instances when such shifts were possible. The subjects of Group B, for whom the 4 additional conflicts were expected occurrences, did not differ materially with respect to these measures. Of the 80 S's, 22 (27 percent) shifted their mode of resolution 30 times during the series. As with the A group this constituted only 9 percent of the instances when such shifts were possible. On the whole the subjects of both groups were quite rigid in maintaining a uniform method of resolving the conflicts.

Factors Related to Shifting of Mode of Resolution.—Shifting may be, in part at least, a function of the kind of resolution which the subject makes on his first trial. Of the 19 subjects in Group A who did shift, 10 (52.6 percent) made Single resolutions on the first conflict trial, whereas of the 61 who did not shift, only 2 (3.3 percent) made Single resolutions. The difference of 49.3 percent is 4.2 times the S.E. of the difference (11.7 percent).

In this connection Lewin has suggested that when a *Type I* conflict is resolved either by an 'oscillation' between the two positions or by approaching one to the exclusion of the other shifts from one kind of resolution to another may occur rather readily on subsequent occasions. He says, ". . . a decision for one goal alters its valence in such a way as to make it weaker than that of the renounced goal" (p. 123). The above figures support this contention; a Single response on the first conflict is nearly always followed by a different response on later conflicts. It is interesting to note, however, that these data were secured from *Type II* rather than from *Type I* conflicts. While this fact does not invalidate Lewin's observation, it does suggest that *the lability of Single reactions may perhaps more appropriately be described as a characteristic of the reaction than of the objectively described field situation.*

It was suggested earlier that the Single and Double resolutions are more closely related functionally to one another than to the Block or Compromise modes, and that the latter pair also possess a functional similarity; *i.e.*, the Single and Double form one *class* of mode of resolution and the Block and Compromise form another class. Evidence for this is derived from analysis of the modes of resolutions between which shifts occurred. Of the 30 shifts which occurred in subjects of Group A, 22 were *intra*-class shifts in the Single-and-Double class; 1 shift was *intra*-class in the Block-and-Compromise class. There were only 7 shifts which might be called *inter*-class shifts, *e.g.*, Single to Block. None of the 7 subjects who made an *inter*-class shift made more than the one shift, whereas the 12 subjects who made *intra*-class shifts averaged 1.9 shifts per subject.

Effects of Expectation on Mode of Resolution.—Analysis of the shifts made by the 22 shifting subjects of Group B leads to the conclusion that expectation of further conflict at first increases and later decreases the number of shifts. Of the total number of shifts, 90 percent occurred on the first two possible occasions and only 10 percent on the last two; corresponding values for Group A are 55.2 percent and 44.8 percent. The difference (34.8 percent) is 3.2 times its S.E. (10.8 percent).

A second effect of expectation appears to be a reduction of the stability of *intra*-class vs. *inter*-class shifts. Whereas 76.7 percent of all shifts with Group A were *intra*-class, in Group B only 46.7 percent were. This difference (30.0 percent) is 2.6 times its S.E. (11.7 percent). With this group there is, as in Group A, a much greater amount of *intra*-class shifting in the Single-Double than in the Blockage-Compromise group. It is apparent that on the basis of the results from Group B there would be no justification for presuming the functional similarity of *B* and *C* as opposed to *D* and *S* resolutions, but Group A, without the extra variable of knowledge about the situation, seems to present a more basic condition from which to determine the existence of such a factor.

A third effect of expectation is a reduction in the number of Single resolutions. In Table 6 are shown, for each group, the number of cases of each mode of resolution on the 5 successive conflict occasions. Group B differs only slightly from Group A on the first occasion, *i.e.*, when the 2 groups were comparable. The former produced more Compromise responses (critical ratio = 1.2) and the latter more Double responses (critical ratio = 1.4). The proportion of total cases giving

TABLE 6

PERCENTAGE OF EACH MODE OF RESOLUTION TO TYPE II CONFLICTS OCCURRING IN EACH GROUP ON EACH OF THE 5 CONFLICT OCCASIONS. GROUP A: UNEXPECTED REPETITION; $N = 80$. GROUP B: EXPECTED REPETITION; $N = 80$

Conflict Trial	Group	Mode of Resolution			
		S	*D*	*C*	*B*
1	A	23.75	7.50	53.75	15.00
	B	32.50	15.00	38.75	13.75
2	A	26.25	8.75	52.50	12.50
	B	35.00	11.25	48.75	5.00
3	A	26.25	8.75	53.75	11.25
	B	36.25	15.00	46.25	2.50
4	A	25.00	10.00	53.75	11.25
	B	36.25	15.00	46.25	2.50
5	A	25.00	8.75	51.25	15.00
	B	36.25	16.25	45.00	2.50

Single responses was almost identical. Examination of the Single column of Table 5 will show, however, that on succeeding occasions there was a marked decrease in number of Single resolutions in Group B, whose members expected further conflicts. The mean proportion of Single resolutions in Group A on conflict trials 2, 3, 4 and 5 was 12.5 percent (σ = 3.7 percent) and in Group B was 3.1 percent (σ = 2.0 percent). The difference between these 2 values (9.4 percent) is 2.2 times its S.E. (4.2 percent). It appears, then, that expectation of future conflicts reduces the proportion of Single resolutions occurring to those conflicts.

Discussion

How much justification there may be for relating these simple motor conflicts to the major emotional ones with which Lewin has dealt is a serious question. It has been fashionable from time to time in the history of psychology to consider such uncomplicated situations as analogues or prototypes of those with which the psychologist is more actively concerned (*cf.* nonsense syllables or the conditioned response). Whether manual motor conflicts and complex emotional ones operate according to the same laws is still a matter for experiment.

But a more basic problem arises in connection with the term 'type' as it has here been used in distinguishing the different kinds of conflict situations. The depiction of a Type I conflict, for example, as a conflict between two antagonistic approach reactions is oversimplified. Inevitably reaction toward one of the goals precludes reaction to the other. Hence, frustration resulting from the relinquishing of the other will be produced. Similarly there are probably few pure Type III conflicts. Successful escape from one of the conflicting situations typically plunges one directly into the opposed conflict situation. Thus it appears that realistic conflict situations are invariably Type IV conflicts with each alternative capable of producing both satisfaction and frustration, and it may be said that the several 'types' differ merely in the relative strengths of their positive and negative reaction systems.

The analysis of conflicts by Lewin has been entirely in the conceptual terminology of his field theory. But a translation can readily be made into actual behavior and the results obtained systematized with concepts derived from reaction psychology. If such a systematization is attempted a minimum of five postulates would be required. These may be briefly stated:

1. The instructions to 'go toward' or 'go away from' establish, respectively, positive (approach) and negative (avoidance) reaction systems to the lights.

2. Practice strengthens these reaction systems.

3. In any approach or avoidance reaction system there is a differential gradient of excitation from the beginning of the reaction to its end. Both increase in strength from beginning to end.

4. Positive and negative gradients which are simultaneously instigated summate algebraically if the two reactions are incompatible.

5. The two reaction tendencies are never exactly equal in strength.

The consequences of these 5 statements or postulates for simple motor conflicts are easily derived. Figure 4 shows the

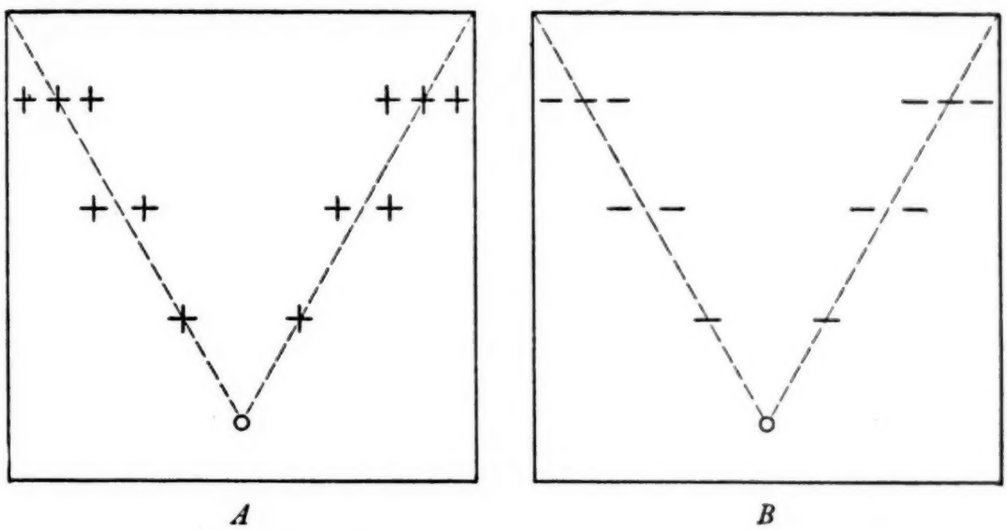

FIG. 4. The gradient of excitation from starting point to end of reaction at the lights. (*A*) Positive gradients of excitation occurring when a Type I conflict is instigated; each plus sign (+) represents an index unit of positive excitation. (*B*) Negative gradients of excitation occurring when a Type III conflict is instigated; each minus sign (−) represents an index unit of negative excitation.

pattern of gradients for each type of conflict. With Type I it is evident that once the reaction to either the right or left has begun because of slight inequalities in the reaction tendencies it will continue because it becomes increasingly strong as it comes nearer to the end, *i.e.*, nearer one light or the other. Thus single responses of direct approach should predominate with Type I conflicts. With Type III conflicts the situation is equally clear. Neither reaction can take place because movement in either direction will be against a

gradient of excitation away from the light. This negative gradient gets stronger as the light is approached and therefore the lowest point of negative excitation is the starting point.[4] Since withdrawal from the field is prevented, the most frequent reaction to Type III conflicts would be blocking. According to this analysis Type II conflicts should represent an intermediate group with respect to the amount of blocking, and this prediction is substantiated by the experimental results.

There would seem to be no greater inherent advantages in one systematic position than in the other. Both Lewin's system and the one here proposed will encompass the conflict phenomena known at present. A choice between them depends upon demonstration that one permits more precise formulation or has greater deductive fertility than the other. A series of investigations is now in progress which is designed to test what are believed to be differential predictions from the two systems of interpretation.

Summary and Conclusions

Four manual motor conflict situations corresponding to Lewin's Types I, II and III, and another (our Type IV) which logically belongs in the same series, were presented to four groups of subjects. The situations were so arranged that unless the subject blocked completely there were only three possible modes of resolution: responding to one stimulus object alone, responding to first one and then the other, or making an altogether new response which represented a compromise between the two incompatible responses. Consideration of the results leads to the following conclusions:

1. Lewin's statement that Type I conflicts (approach-approach) are usually resolved by responding to one or both of the stimulus objects was verified.

2. Indirect verification was given to his statements that Types II (approach-avoidance) and III (avoidance-avoidance) conflicts are resolved by 'withdrawal from the field.' Both

[4] The operation of such a negative gradient has been experimentally demonstrated and discussed by Bugelski, R. and Miller, N. E., A spatial gradient in the strength of avoidance responses. J. Exper. Psychol., 1938, **23**, 494–505.

types produced more blocking and compromise responses (III more than II) than did Type I.

3. These results are shown to be consistent with deductions based either on Lewin's field theory or on a set of five postulates deriving from reaction psychology.

4. The single and double modes of resolution are closely related to each other functionally as are the blocking and compromise resolutions.

5. Repeated presentation of Type II conflicts indicated a high degree of intra-individual consistency in mode of resolution.

6. Knowledge that a conflict situation would recur did not greatly influence the mode of conflict resolution nor the degree of consistency of response.

(Manuscript received May 25, 1938)

A SPATIAL GRADIENT IN THE STRENGTH OF AVOIDANCE RESPONSES [1, 2]

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I. Relation of Problem to Theories of Conflict and Learning

Two basic assumptions in recent theories of conflict [3] are: (1) that the tendency for an organism to approach a goal is stronger the nearer the organism is to that goal; and (2) that the tendency for an organism to avoid a potentially noxious stimulus is stronger the nearer the organism is to that stimulus. The first of these assumptions, the hypothesis of an approach or goal gradient, has been fairly well supported by relatively direct experimental evidence (**4, 12, 13**). Since the second of these basic assumptions, the hypothesis of a gradient of avoidance responses, had not yet been supported by any such evidence, it seemed desirable to subject this hypothesis to direct experimental test.

A verification of the existence of a gradient of avoidance responses would be relevant also to learning theory in that it would tend to round out the pattern of evidence which previous studies have supplied on the problem of reinforcement. Thorndike (**14**) has demonstrated that the effect of reward spreads from more immediate to more remote connections, becoming weaker the more remote the connections. Wolfle (**15**) has shown that the strength of conditioning is weaker

[1] The term 'spatial gradient' is not defined as a gradient existing independently in space, but rather as a gradient in the strength of an organism's reactions to the stimuli (both external and internal) which play upon it when it is at different points in space.

[2] The experimental work on this article was done at the Institute of Human Relations, Yale University. The results were reported in part (7) at the meeting of the American Psychological Association, Minneapolis, 1937.

The authors are grateful to Mr. Judson S. Brown for criticizing the manuscript.

[3] Hovland and Sears (2), Hull (5), Lewin (6), Miller (7, 8).

the further the conditioned stimulus is removed from a point near simultaneity with the unconditioned stimulus. Hull (**3**) has postulated that excitatory tendencies are weaker the further the organism is from the goal. Miller and Miles (**9**) have pointed out the similarity in these statements and have suggested that they can be conveniently integrated by the assumption that "the effect of a reinforcing stimulus varies inversely as the remoteness of that stimulus from the act which is reinforced." Muenzinger, Dove and Bernstone (**10**) have recently secured evidence which seems to support this assumption by demonstrating that the goal gradient is really bi-directional and hence more similar to the phenomena studied by Thorndike and Wolfle than has hitherto been suspected. An additional similarity would be demonstrated if it could be shown that a gradient in the strength of response is produced irrespective of whether approach is being reinforced by reward, or avoidance by punishment.[4] This would further support the hypothesis that a single factor, such as the generalization of reinforcement, is basic to all of these phenomena.

II. Apparatus and Procedure

The *apparatus* employed was devised by Miller (**7**) for use in measuring conflict. A schematic diagram of it is shown in Fig. 1. The rat ran in a single alley 5 inches wide, 5½ inches high and 6½ feet long. The floor of this alley consisted of a grid of .025" stainless steel wire stretched across an air gap at 3/8 inch intervals. The hinged top of the alley was covered with wire mesh. One end of the alley was made distinctive by a round hole 1¼ inches in diameter through which shone the rays of a 10 watt electric light. The room was relatively dark so that this was the chief source of light in the alley. To the inside of the top at this end was fastened a 10 by 6 inch plate of glass to prevent the rats from jumping up and clinging to the top when shocked.

The shocks used in this experiment were administered at the rate of 20 square-wave, D.C. impulses per second. The strength of current was held constant at 0.8 milliamperes by a simple vacuum tube device (**11**) which compensated for all ordinary fluctuations in the subject's resistance. The duration of shock (1 second) was controlled by a small pendulum.

The details of the running behavior of the rat were recorded accurately in the following manner. An ordinary rubber band, 4 mm. broad, encircled the animal behind

[4] We do not mean to use approach and avoidance as fundamental dichotomies nto which all responses can be pigeon-holed but merely to use them as convenient examples of obviously incompatible responses easily measured in a controlled experimental situation. In fact, positive results in the present experiment would tend to demonstrate that these phenomena are fundamentally similar rather than dichotomous.

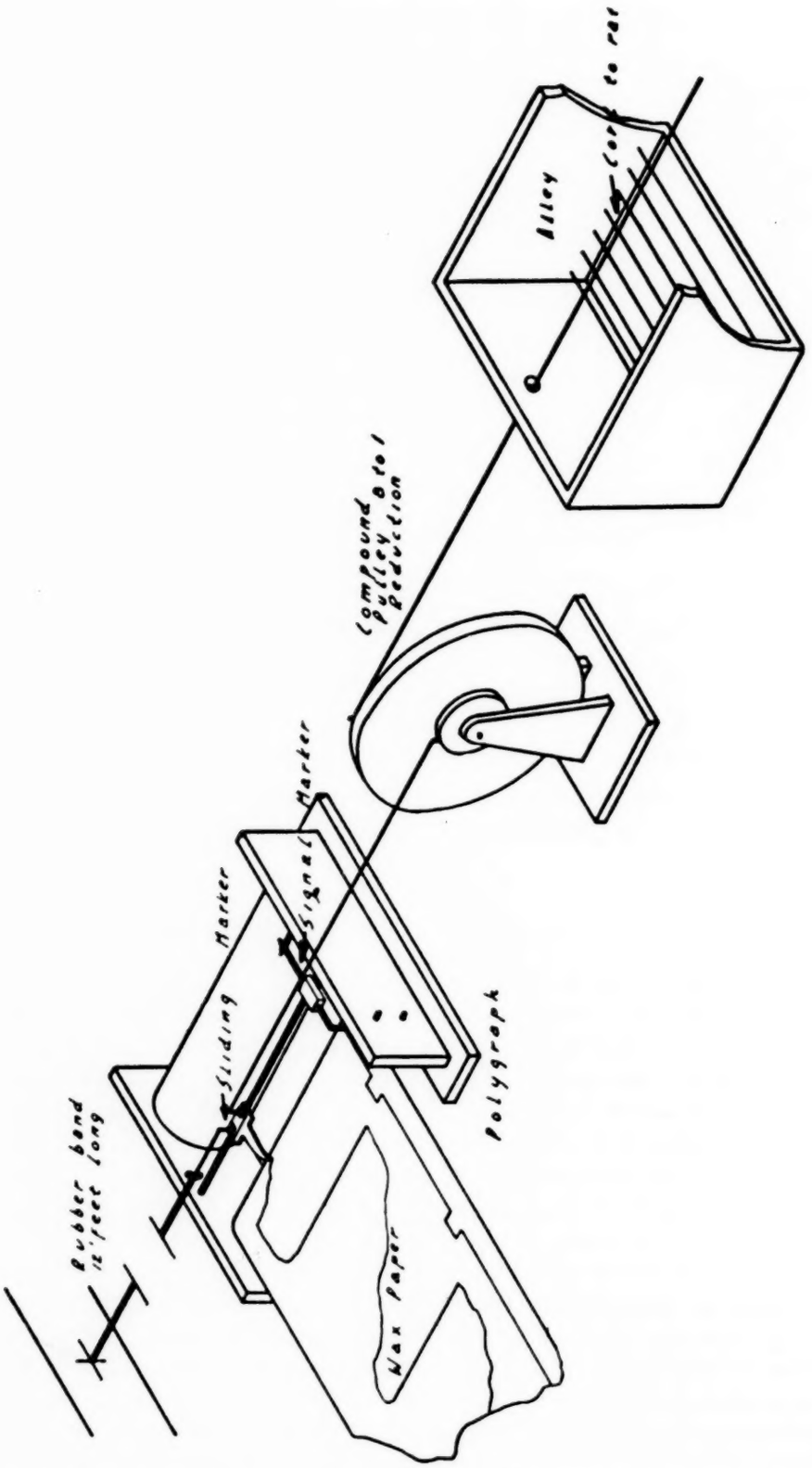

FIG. 1. Schematic diagram of the apparatus for recording in exact detail the locomotion of the rat in the alley. The cord from the large wheel of the compound pulley was coupled to a short leader of watch chain which was attached by a ring-snap to an ordinary rubber band encircling the animal behind its forelegs. The effective length of the elastic strip responsible for taking up all slack in the system was increased from 12 to 24 feet by a block and tackle not indicated in the diagram.

its forelegs. To this was attached a ring-snap on a short leader of watch chain coupled to the end of a length of light, flexible fish line. This line was wound around and attached to the large wheel of a compound pulley. From the small wheel of this pulley a similar line ran to a sliding stylus point which marked on the wax paper of a polygraph driven 1.88 cm per sec. by a synchronous motor. This line was held taut by a light strip of rubber whose effective length was 24 feet. Since the large wheel of the pulley arrangement gave the rats an 8 to 1 mechanical advantage in operating the easy moving stylus, barely enough tension was needed on the line to keep it taut and out of the way of the animal's feet. After a few minutes habituation, most of the animals payed surprisingly little attention to their harness.

The *subjects* were 30 albino rats approximately 75 days old at the time of the experiment.

Our *procedure* was to habituate the rats to the alley, train them to avoid the lighted end, and then measure the strength of their avoidance responses at various distances from that end.

Prior to the experiment proper the rats in groups of 10 were left for habituation in the alley over night without harness. On the next afternoon each rat (alone) was given 15 minutes of habituation to the harness in the alley.

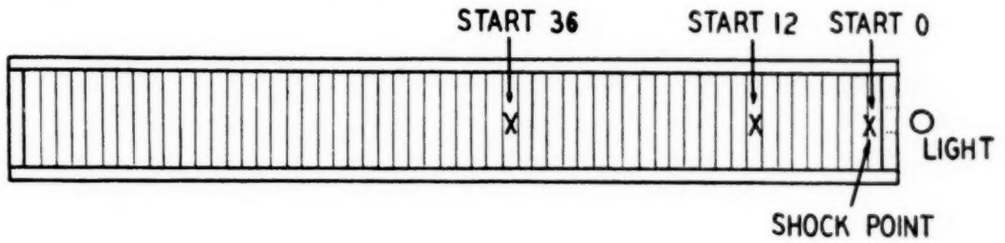

FIG. 2. The relative positions of *start 0*, *start 12* and *start 36* in the alley.

The rats were trained to avoid the lighted end of the alley in the following manner. They were placed gently at the extreme end of the alley near the light and facing it. They were allowed to remain there for 5 seconds after which an 0.8 milliampere shock was administered to them for one second. This caused them to retreat immediately. After 25 seconds of unmolested freedom in the alley, they were gently picked up from wherever they were and held in the hand for 30 seconds. The same procedure was then repeated three more times.[5]

After each rat had been trained to avoid the lighted end of the alley, he was placed for 12 minutes in an individual cage with food and water available.

At the end of this 12 minute period each animal was given three test trials without shock. Each trial was given from one of three starting positions. The three positions used were: (*a*) *Start 0* in the original shock position immediately in front of the light, (*b*) *Start 12* facing the light 12 inches from the original shock position, and (*c*) *Start 36* facing the light 36 inches from the original shock position. These three positions in the alley are illustrated in Fig. 2.

[5] The relatively weak light, by itself, was a neutral stimulus at the beginning of the experiment. During habituation the animals investigated all portions of the alley and as often as not spent the night next to the opening through which the light entered. After several shocks, however, the animals had to be held facing the light for their five-second pre-shock orientation period. Control animals, that were shocked at the opposite end of the alley, learned to avoid that end and ran *toward* the light.

On the first test trial the animal was placed in the alley at one of the three positions. The moment of placement in the alley was recorded by a magnetic marker on the polygraph. The animal was left in the alley for 30 seconds during which the exact extent and speed of any movements in either direction were recorded. At the end of this 30 seconds he was taken out and held in the hand for 30 seconds. Then he was given two more similar trials beginning at the two other starting positions.

In order to administer the 3 trials, each with a different starting position, in a perfectly balanced order, the animals were divided into separate squads. Since there are 6 permutations of 3 things taken 3 at a time, dividing the 30 animals into 6 squads of 5 rats apiece enabled us to run one group in each of the 6 possible orders of the 3 starting positions.

III. Results

Avoidance Tendency.—It will be remembered that all 90 of the test trials were administered without shock. In 82

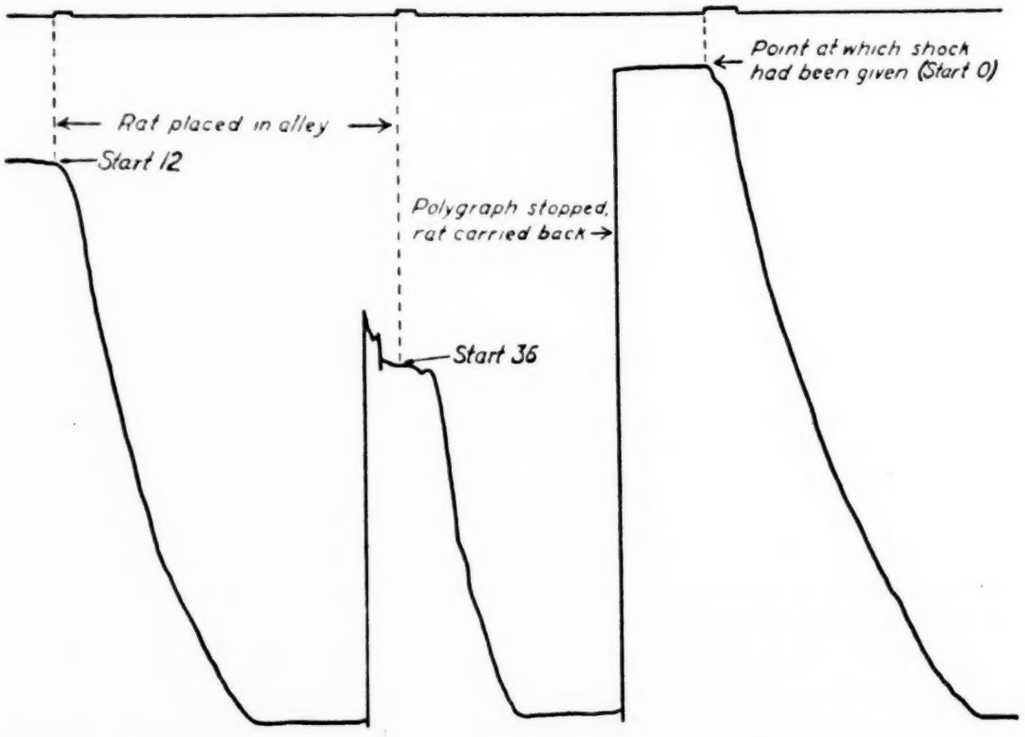

Fig. 3. A sample record of the three test trials of one rat.

percent of these test trials the animals ran away from the end where they had been shocked.[6] In only 18 percent of the trials did the animals fail to start within 15 seconds.[7] In none of the 90 test trials did any animal run towards the end where he had been shocked. It is thus evident that the four

[6] All of these animals actually started within 10 seconds.

[7] These animals were distributed among the various positions as follows: 2 from *Start 0*, 4 from *Start 12*, and 10 from *Start 36*.

training trials had established a definite tendency to avoid the end of the alley where shock had been administered.

General Pattern of Retreat.—Before considering the data bearing directly on the problem under investigation, some of the more general characteristics of the pattern of retreat will be noted briefly. A typical record of one animal's three test trials is shown in Fig. 3. Most of the runs, about 80 percent, were of the relatively smooth or continuous type illustrated by this record. Some, about 20 percent, however, were of a

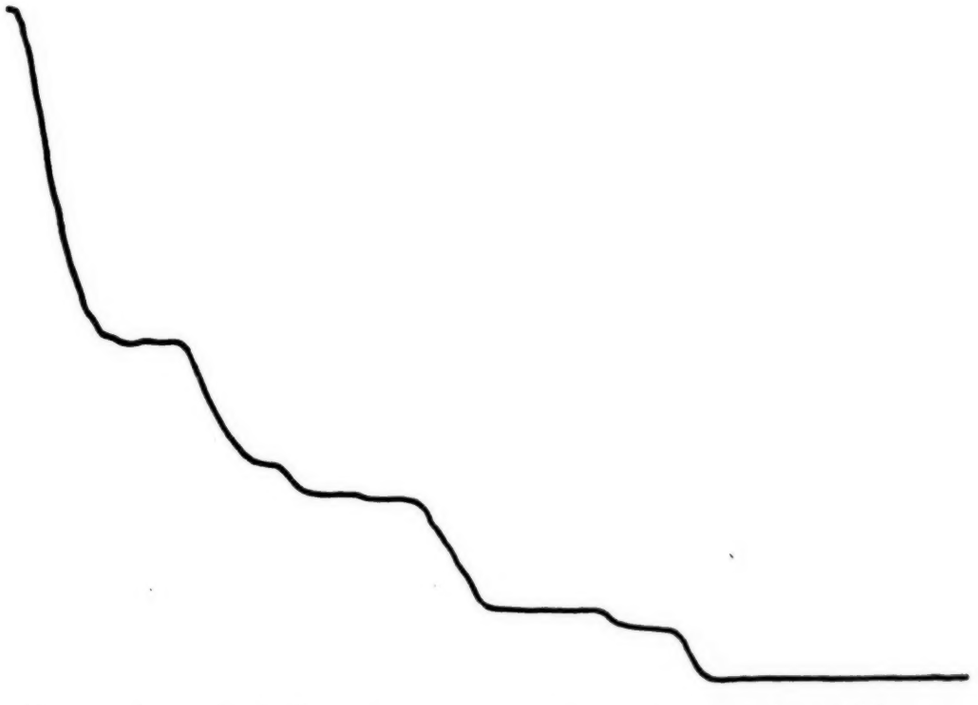

FIG. 4. A record of a discontinuous run. This was a test run of one of the control animals that had been shocked at the dark end of the alley and ran toward the light. In this trial the animal ran approximately four feet or two-thirds the length of the alley.

definitely stepwise or discontinuous type of run. A good example of a record of such a run is illustrated in Fig. 4. One thing was fairly characteristic of the records of all runs whether they were smooth and continuous or steplike and discontinuous. This was that the change from standing to running tended to be relatively abrupt. The abruptness of starting and stopping is evident in Fig. 3, particularly in the middle curve where the animal remained practically motionless for a few seconds after being released in the alley and then suddenly started to run fairly rapidly. It is even more

evident in Fig. 4 where it is obvious that the relatively sudden stops could not have been caused by nearness to the end of the alley. Such suddenness of shift from stopping to running was characteristic of most of the runs recorded.

Starting Time.—The starting time of each trial was arbitrarily defined as the length of time required by the rat to run 3 inches after being placed in the alley. In Fig. 5 the

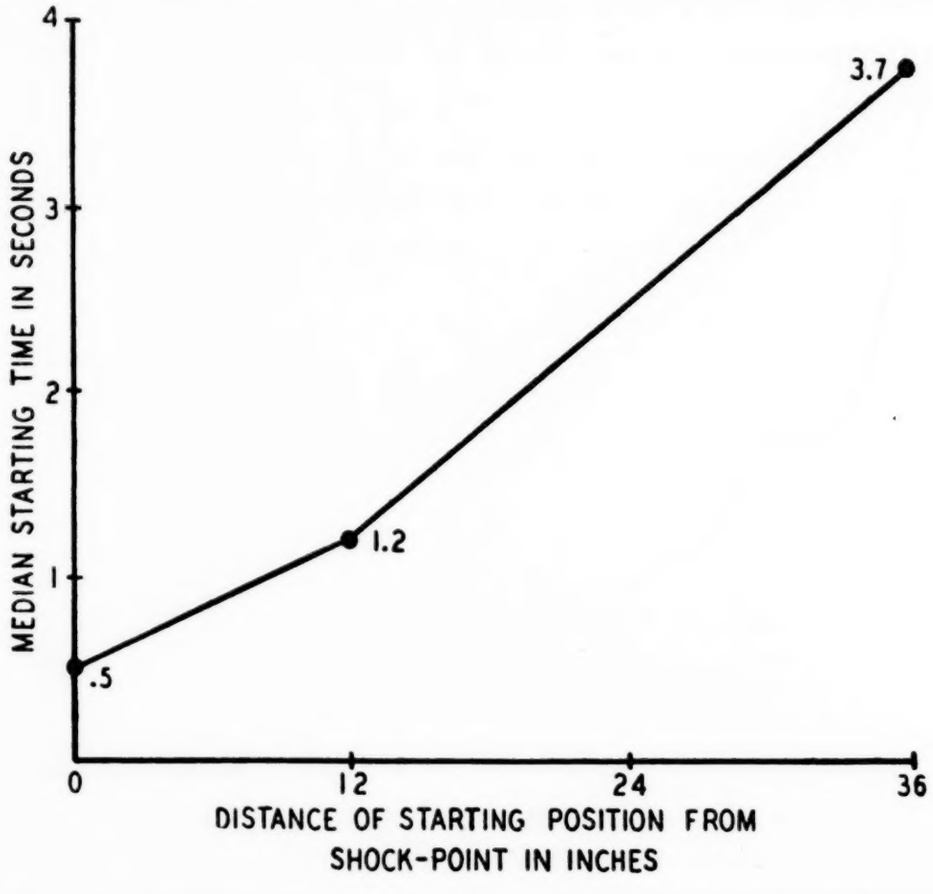

FIG. 5. Starting time as a function of distance from shock-point. Each point is based upon 30 measures. Thirty rats were each given three test trials, one from each of the three starting positions. The order of administration of these trials was varied in a balanced manner.

median starting time is plotted for each of the 3 starting positions. It can be seen from this figure that the starts were slower the farther the animals were placed in the alley from the point at which they had received shocks.

Because of the extreme skewedness of the distributions of the time scores, a consideration of the reliability of these results in terms of the categories of a Bernoulli distribution

will be the most appropriate. Seventy percent of the animals started more slowly when placed in the alley 36 inches from the shock point than they did when placed in the alley right at the shock point. The probability of such a proportion being produced by chance alone is less than .01. Sixty-seven percent of the animals started more slowly 36 inches from the shock point than they did 12 inches from that point. The

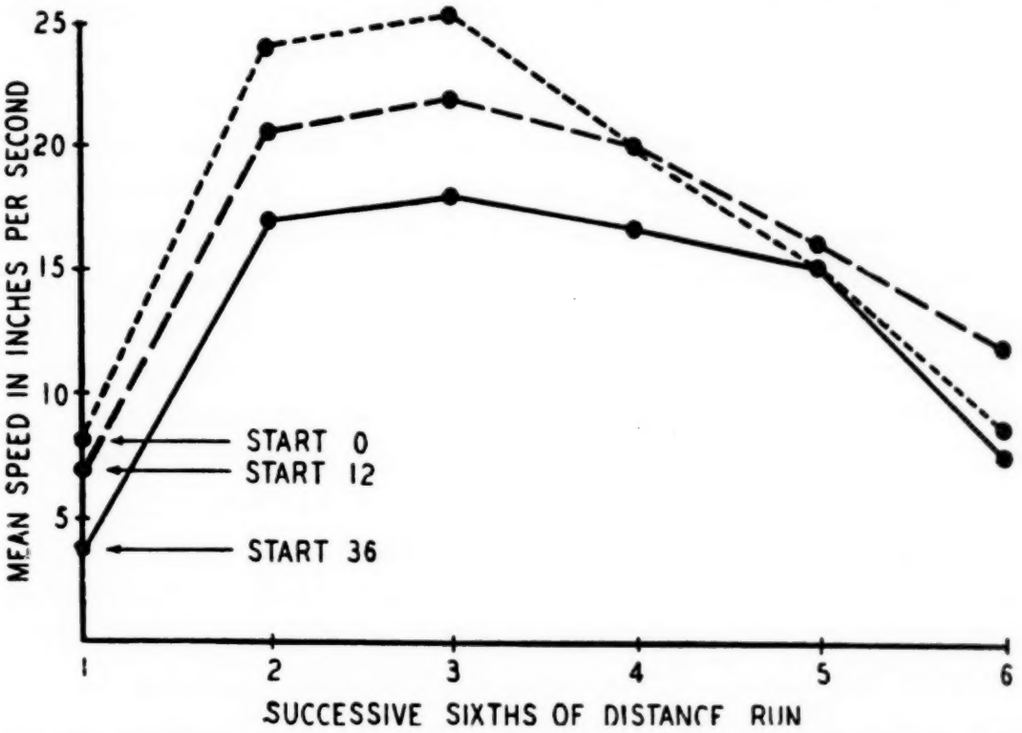

FIG. 6. Vincent curves for the speed of the runs from each of the three starting positions. These curves are based upon the records of only those animals which actually did run away. The portion of the record utilized was that between the point at which the animals first started to run and that at which they last stopped running. This distance, the length of the retreat, was divided into six equal parts and the speed for each sixth was computed and averaged with the respective sixths of other animals' retreats from the same starting position.

probability of such a proportion's being produced by chance alone is .03.

The fact that the farther the start is from the point associated with shock, the longer the animals wait before commencing to run away, supports the hypothesis of a spatial gradient in the generalization of avoidance responses.

Running Speed.—In Fig. 6 are plotted Vincent curves of running speed for the retreats that the animals made from each of the three starting positions. These curves include

only those animals which actually did run away and are based on only the portions of the record between the point at which the animal first started to run and that at which it last stopped running. This distance, the length of the retreat, was divided into six equal parts and the speed for each sixth was computed and averaged with the respective sixths of other animals' retreats from the same starting position.

From a comparison of the different curves, it is apparent that the further the animals were started from the point they had been conditioned to avoid, the slower they ran. This difference is statistically reliable for the beginning of the runs but less reliable towards the end. The difference between the mean speed of the first sixth of the runs starting from *Start 0* and from *Start 36* is 3.3 times its standard error; that for the second sixth of the runs is 2.2 times its standard error. The difference between the mean speeds of the first sixth of the runs from *Start 12* and *Start 36* is 2.2 times its standard error. The rest of the critical ratios are lower.

It should be noted, as was pointed out above, that the starting times of all trials and the records of those trials in which the animal did not run at all were both excluded from the data upon which these differences are based. Had starting time been included in calculating the speed for the first sixth of the run, the differences for this portion would have been still greater because, as will be remembered, the starts were slower on the trials beginning farther from the shock point. Had the scores of the animals failing to run at all (whose speeds would have been zero) been included in the averages, the differences would likewise be made greater because more animals (2, 4, and 10 respectively) failed to run on the trials whose starts were farther from the shock point.

The fact that even after the animals get started they tend to move more slowly the farther they are placed in the alley from the point at which they have been shocked, is additional evidence for a spatial gradient in the strength of avoidance responses.

The two measures that have been used, starting time and initial running speed, are relatively pure measures of the effects

of a spatial gradient in the strength of the reinforcement of avoidance responses. When either the starting time or the initial running speed of a trial beginning at one distance from the point of reinforcement is compared with the starting time or running speed of a trial beginning at a different distance, only one variable, distance from the point of reinforcement, is being varied. When, however, the speed of locomotion of one section of a trial is compared with the speed of locomotion of a different section of that trial, an additional variable, distance that the animal has already run, is also being varied. This introduces the possibility of complications from the effects of two factors: (1) a warming up effect in the initial portions of the run and (2) an anticipatory stopping tendency towards the end of the run. As is clearly evident in Fig. 6, during the first parts of each run the effects of warming up definitely overrode those of the gradient of reinforcement. The differences between the speeds in the first and third sections of the runs are 5.0, 5.7 and 6.2 times their standard errors for starts *0*, *12* and *36* respectively. During the remainder of each run, there was a progressive tendency for the animals to slow down, the differences between the speeds in the third and sixth sections of the runs from the 3 starting positions being respectively 4.7, 2.9 and 1.5 times their standard errors. It is, of course, impossible to be certain how much of this decrement was produced by a gradient of reinforcement and how much was the result of an anticipatory stopping tendency.[8]

IV. Summary

1. A basic assumption in various recent theories of conflict is that the tendency for an organism to avoid a stimulus object is stronger the nearer the organism is to the stimulus object

[8] In this experiment the effects of a gradient of reinforcement would be expected to be opposed by those of warming up and to be augmented by those of anticipatory stopping. In the approach situation, studied by Professor Hull (4), these relationships would be reversed: the effects of the gradient should summate with those of warming up and be opposed by those of anticipatory stopping. It is interesting to note that it is at the *beginning* of the run in this experiment and at the *end* of the run in Professor Hull's that the changes in speed of locomotion are opposite to what would be expected if a gradient of reinforcement were the *only* factor operative throughout the different sections of the run.

which must be avoided. The purpose of the present experiment was to secure direct evidence on this principle.

2. Thirty albino rats were first given four training trials in which they ran away from a brief shock received at one end of a straight alley. Then, in test trials without shock, they were placed in the alley at various distances from that end and the pattern of their running away was recorded directly, in exact detail, on a polygraph.

3. As general observations on the pattern of behavior under the conditions of the test trials it was noted that: (*a*) *In both starting and stopping, the transition between running and non-running was almost always quite abrupt;* and (*b*) *The rate of locomotion tended to increase throughout the initial two-fifths of a run and to decrease progressively during the final three-fifths of the run.* The fact that, during the first portion of the run, the 'warming up' effect was strong enough to override the effects of an avoidance gradient, led to the conclusion that comparing the speeds of different portions of the *same* run is a poor method of investigating gradients in the strength of approach or avoidance responses. Therefore, a different method was used.

4. Direct evidence was secured for the existence of a spatial gradient in the strength of avoidance responses in that: (*a*) *When placed in the alley farther from the original shock point, the animals tended to wait longer before starting to run away than they did when placed nearer to this point;* and (*b*) *Even after getting started, the animals placed farther from the shock point tended to run less rapidly than they did when placed nearer to this point.*

This evidence is relevant to theories of learning, as well as conflict, in that it tends to support the generalization that "the effect of a reinforcing stimulus varies inversely as the remoteness of that stimulus from the act which is reinforced." [9]

(Manuscript received May 25, 1938)

[9] Facts of the type reported by Guthrie (1) suggest that this principle may have to be reduced to some more fundamental one, such as a formulation in terms of overlapping 'identical elements,' in order to be applicable to situations in which a dominant role is played by verbal and other similar stimuli produced by those responses of the organism which are not too closely bound to any fixed sequences.

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RESISTANCE TO EXTINCTION AS A FUNCTION OF THE NUMBER OF REINFORCEMENTS [1]

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The present paper is an attempt to give a quantitative description of one of the important relationships postulated by conditioned-response theories of learning. An extensive experimental literature, comprehensively reviewed by Hilgard (**2**), points to the essential similarity between 'reward' learning and 'reinforcement' learning, suggesting the possibility of deriving both types from a single set of postulates. Hull (**5**, **6**) has attempted the theoretical derivation of a large number of the mechanisms of adaptive behavior, notably those of trial-and-error learning, from postulates based on a number of the phenomena found in conditioning. The predictive value of such a theoretical system depends in large part on a knowledge of the quantitative nature of the phenomena in question, particularly reinforcement, extinction, and spontaneous recovery.

The strength of a response tendency as some function of the amount of reinforcement given it, is a relationship whose determination is dependent on the method used for testing the strength of the tendency. The most commonly used indicators are: magnitude of response, frequency of appearance of response, latency of response, and the resistance of the response to experimental extinction. The last mentioned measure was suggested by the following statement of Pavlov (**7**):

> ". . . The greater the intensity of the excitatory process, the more intense must be the inhibitory process to overcome it, and therefore the greater number of unreinforced repetitions necessary to bring about complete extinction" (p. 61).

[1] This investigation is a part of a coordinated research program of the Institute of Human Relations, Yale University. It was carried out under the direction of Professor Clark L. Hull, to whom the writer is greatly indebted for interest and assistance in the problem.

Skinner (**10**) has suggested that resistance to extinction may be the *only* appropriate measure of conditioning, particularly since it has been shown to be the most reliable index of 'over-conditioning.' As yet, however, very little work has been directed specifically to the relation between the *amount* of reinforcement and resistance to extinction.[2] Skinner (**8**) simply reports a ratio of 20 extinction responses to one reinforcement, with immediate extinction; and Youtz (**11**), using a modified form of the Skinner apparatus, has tested the effect on extinction of two different amounts of reinforcement. In the latter study the results were indicative of a negatively accelerated gradient, although two points on a curve are hardly sufficient to indicate its true nature.

The present experiment was designed to determine four points on this gradient by testing resistance to extinction after four different amounts of reinforcement. A second and distinct problem investigated was the corresponding amounts of spontaneous recovery from extinction after an interval of one hour.

Subjects and Apparatus

Subjects in the experiment were 140 male albino rats within the age range of 60 to 100 days. During the experiment, twelve rats were discarded for failure to learn.

The apparatus used was of the type employed by Skinner (**9**) and Youtz (**11**), and an exact duplicate of that described in detail by Ellson (**1**). It consisted of four separate experimental boxes, partially soundproofed, and vacuum-ventilated. Each box contained an animal compartment which measured a cubic foot inside. The rear wall of the compartment was formed by a panel through which a small horizontal bar (Fig. 1) could be quietly inserted into the animal's presence by the experimenter manipulating a lever outside the box. A shutter automatically covered the aperture in the panel when the bar was retracted. When the bar was inserted it extended into the compartment one-half inch beyond the panel. It required a downward pressure of fifteen grams and a displacement of not less than three-sixteenths of an inch to activate a mercury-cup switch behind the panel. The mercury contact completed a circuit which in turn activated a recording marker mounted on a synchronous-motor-driven polygraph. On top of the box outside was a food magazine which contained small specially prepared pellets of food, each weighing .05 grams. The wiring and construction of the box were so arranged that a depression of the bar by the rat inside the

[2] Hovland (**3**) has recently shown differential reinforcement to yield a negatively accelerated extinction curve, using amplitude of response as an indicator. The fact that his results, obtained from conditioned galvanic-skin responses, reveal a function similar to those obtained from problem-box learning experiments, lends weight to the assumption that common laws operate in both situations.

box caused one pellet of food to be released from the magazine. The pellet fell through a tube into a small food tray placed on the floor of the compartment directly underneath the lever. The same stroke activated a polygraph marker which automatically recorded the number and time of all responses. In this experiment the eating of one

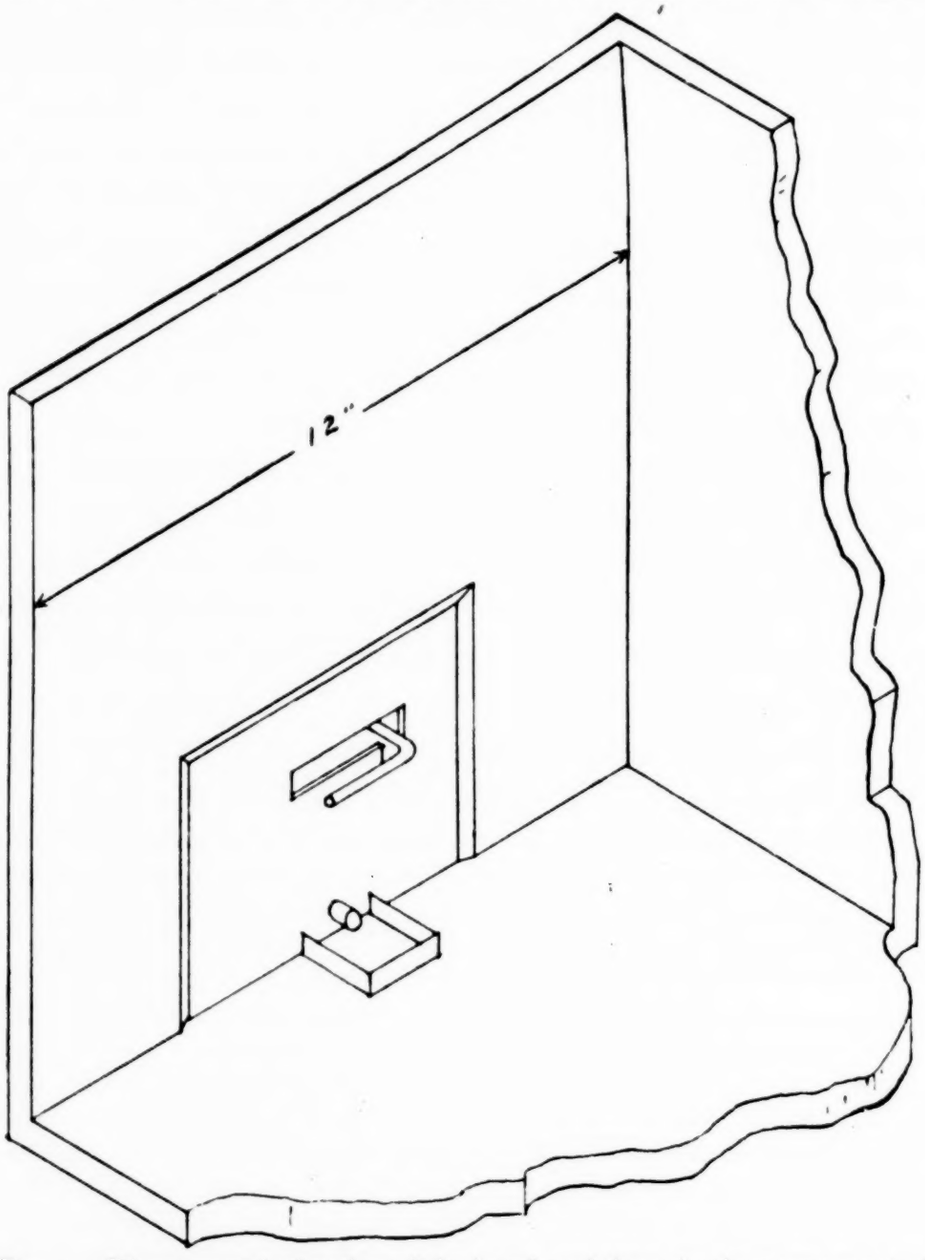

FIG. 1. Diagrammatic drawing of the interior of the animal compartment of the experimental boxes, with the horizontal bar in position for operation by the rat. The tip of the glass tube through which the food pellet passes, and the food tray, are shown directly underneath the bar. The shutter which automatically closes the aperture when the bar is retracted is not shown in the diagram.

pellet was considered as one reinforcement. It was possible to disconnect the magnetic food-release mechanism so that during the extinction series no food was delivered upon the rat's depression of the bar, although the responses still were recorded on the polygraph in the usual manner.

PROCEDURE

The animals were run in squads of four. Each squad was fed for one week previous to the experimental period at the same hour of the day at which training was to take place. On the first four days of this week they were fed in their individual living cages; on the last three days they were fed in the experimental boxes, for one hour on the fifth and sixth days, and for one-half hour on the seventh day.

The experimental period itself was broken up into three days. On the first day, the four rats were put into the boxes and fed 60 pellets in groups of 10 pellets. The feedings were spaced five minutes apart, the animals spending each interval in the living cages. The pellets were given by the operation of the food-release mechanism by the experimenter. Receiving one pellet at a time in this way, the rats soon learned to respond to the characteristic noise, or click, of the food mechanism by going to the food tray and eating the pellet deposited there. After sixty pellets the rats were returned to their individual cages.

On the next day, 23 hours later, the rats were placed in the experimental boxes and given 30 pellets in immediate succession in the same manner, after which they were returned to their cages. Ten minutes later they were again placed in their respective experimental boxes and the horizontal bar was quietly introduced into the compartment by the experimenter. Until this time the rats had had no experience with the bar, and to facilitate learning a small amount of wet mash had been smeared on it. In some cases it was found necessary to open the rear door of the box behind the panel (not visible to the rat) and by means of an electric fan blow air across wet food into the compartment through the bar entrance, so that the rat would more quickly investigate the region of the bar. Failing this, a screwdriver, whose tip was daubed with a bit of moist food, was inserted through the aperture to attract the attention of the animal. In any case, the rat seemingly quite by accident would press the bar once or twice, thereby receiving a pellet of food as reinforcement; and since the bar-pressing response was thus reinforced, it was repeated. In this way one group of 35 rats was allowed to obtain five pellets of food; a second group, 10 pellets; a third group, 30 pellets; and a fourth group, 90 pellets. The four groups were approximately equated as to learning time for the first five responses. This is shown in Table 1.

TABLE 1

COMPARATIVE LEARNING TIME OF EXPERIMENTAL GROUPS

Equivalence of experimental groups as to learning time can be judged only on the basis of the time to learn the first five responses. Total learning time for the last three groups is also presented.

		Group (Number of Reinforcements Given)			
		5	10	30	90
Learning time for first 5 responses in minutes	Mean.....	3.1	3.3	3.2	3.5
	σ_m.....	.56	.56	.57	.66
	Median.....	1.8	2.4	2.0	1.9
Learning time for all responses in minutes	Mean.....	3.1	6.2	11.5	29.6
	σ_m.....	.56	.79	.91	1.32
	Median.....	1.8	4.5	10.0	27.1

On the third day, twenty-two hours after learning, the rats were placed once more in the experimental boxes for the first extinction series. The bar was introduced as in learning, but since no food followed depression of the bar the rats soon ceased responding to it. Complete extinction, of course, was never reached. Instead an arbitrary criterion of extinction was chosen, namely, a period of five minutes during which no responses to the bar were made.

TABLE 2

RESULTS OF FIRST EXTINCTION. MEASURES OF RESISTANCE

All measures are based on 35 animals in each reinforcement group. Rate of response is obtained by dividing total time by number of responses and was calculated for each rat.

Measure of Resistance to Extinction		Group (Number of Reinforcements)			
		5	10	30	90
(*a*) Number of responses	Mean	19.0	35.0	48.3	62.7
	σ_m	4.3	7.4	4.4	6.4
	Median	9.0	23.0	43.0	60.0
(*b*) Time to reach criterion (minutes)	Mean	7.9	15.0	17.1	20.6
	σ_m	1.3	1.8	2.1	2.0
	Median	7.2	14.5	14.1	18.9
(*c*) Rate of response (in minutes)	Mean	.64	.64	.47	.40
	σ_m	.04	.04	.08	.04
	Median	.55	.54	.37	.35

Exactly one hour after the termination of the first extinction series (the interim being spent in the cages), the animals were returned to the boxes for a second extinction to the five-minute criterion. The responses made in this series constitute a measure of spontaneous recovery.

Resistance to experimental extinction was measured in three ways: the total number of responses during extinction; the total time required to reach the five-minute criterion; and the rate of response, or the mean time elapsing between successive responses.

RESULTS

In a qualitative sense, the statement of Pavlov is confirmed; the greater the reinforcement, the greater the resistance to extinction. The quantitative results are given in the accompanying tables and graphs.

First Extinction; Measures of Resistance to Extinction

Youtz (11) found that the number of responses made in resistance to extinction was a more reliable index of original reinforcement than extinction time or responses per minute, but Ellson's (1) results indicate extinction time to be the most

reliable measure. Data from the present experiment, shown in Table 3, favor the number of non-reinforced responses as a measure, although it may be clearly seen that extinction time differentiates the two small reinforcement groups (5 and 10) better than any other measure. In general, however, the number of non-reinforced responses is more closely correlated with differential reinforcement than are the other two measures.

The results of the first extinction series according to all three measures are presented in Table 2, and the reliabilities of the several differences are shown in Table 3. It will be seen

TABLE 3

RELIABILITY OF MEASURES OF RESISTANCE TO FIRST EXTINCTION

Critical ratios (Diff./σ diff.) of the means for paired groups of reinforcement

Paired Reinforcement Groups	Measures of Resistance to Extinction		
	No. of Responses	Total Time for Extinction	Rate of Response
5 reinf. vs. 10	C.R. = 1.87	C.R. = 3.20	C.R. = 0
10 reinf. vs. 30	= 1.55	= .76	= 1.89
30 reinf. vs. 90	= 1.88	= 1.21	= .78
5 reinf. vs. 30	= 4.80	= 3.72	= 1.89
10 reinf. vs. 90	= 2.84	= 2.08	= 4.21
5 reinf. vs. 90	= 5.71	= 5.31	= 4.21

that there is a fair degree of statistical reliability of the differences, especially those of total time and number of responses, in spite of a large amount of variability in the original scores. It may be concluded that all measures reflect a positive and consistent relation between resistance to extinction and amount of reinforcement. These reliabilities of the measures are similar to those found by Youtz (**11**) and Ellson (**1**), both of whom employed subjects in statistically significant numbers.

The ratio of non-reinforced responses to reinforcements becomes progressively smaller with increasing amounts of reinforcement. Computed from the mean values in Table 2, the ratios are 3.8 to 1, 3.5 to 1, 1.6 to 1, and .7 to 1 for 5, 10, 30, and 90 reinforcements respectively. It is not to be expected that these ratios should approach the 20 to 1 ratio

reported by Skinner (8), inasmuch as he allowed no time to elapse between reinforcement and extinction.

Because of the fact that there were some animals in the lower reinforcement groups which made *no* responses during

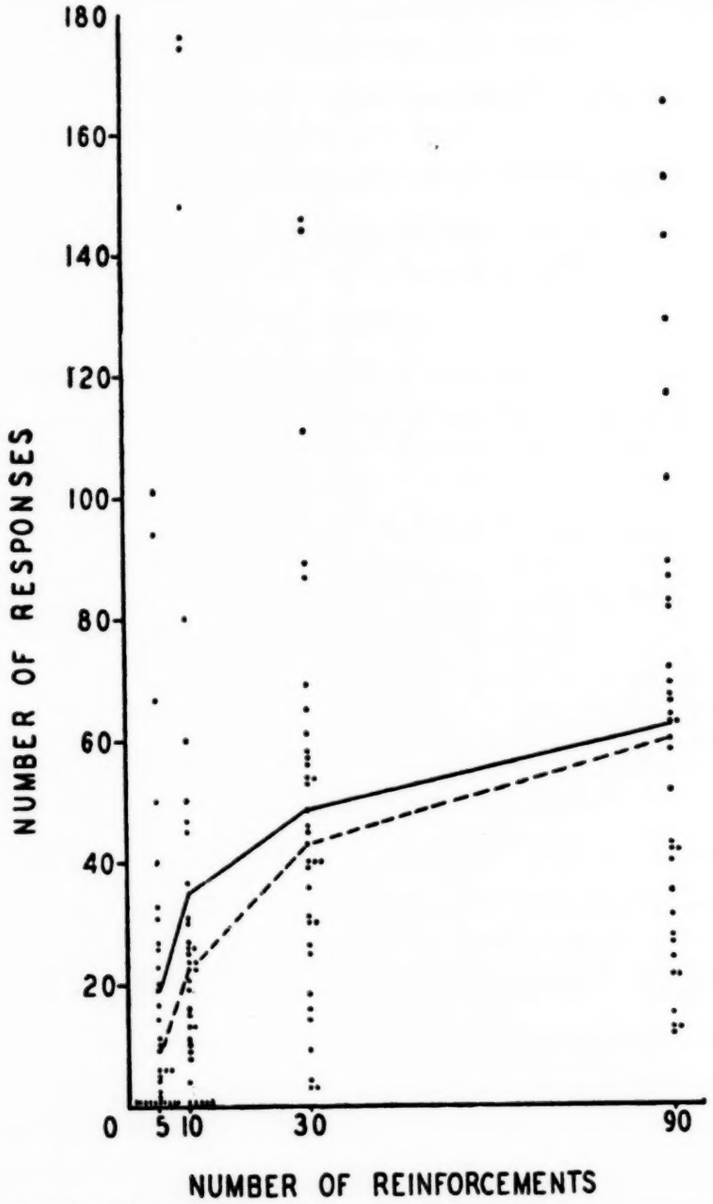

FIG. 2. Dot distribution for the first extinction, showing the number of responses made in resistance to extinction. Each dot represents one animal. The heavy line indicates the mean, the broken line, the median. The wide scatter of this distribution is also characteristic of the extinction time scores, which are not shown.

extinction, the distributions of the 5- and 10–reinforcement groups are considerably skewed toward the upper end. Since the median values necessarily are less subject than the mean

values to this type of distortion, it is very likely that the medians represent a more stable measure of central tendency than do the means. The dots in Fig. 2 present a typical picture of the distribution. Figures 3 and 7 show the actual

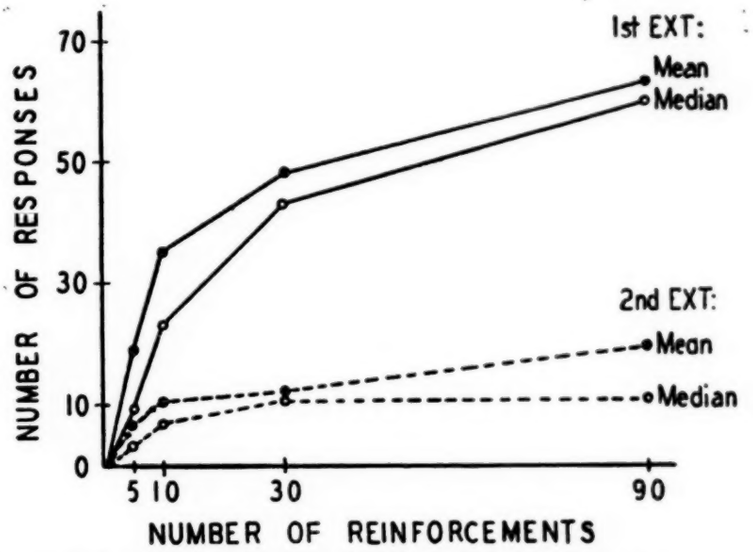

FIG. 3. Graph showing the mean and median number of responses made in resistance to extinction. The upper pair of curves represents the first extinction, and the lower pair, the second extinction one hour later. Each point represents the central tendency of the scores from 35 animals.

curves of the two to be quite similar in shape, though the medians are consistently lower. Approximately the same kind of relationship is shown by Fig. 4 to hold for median and

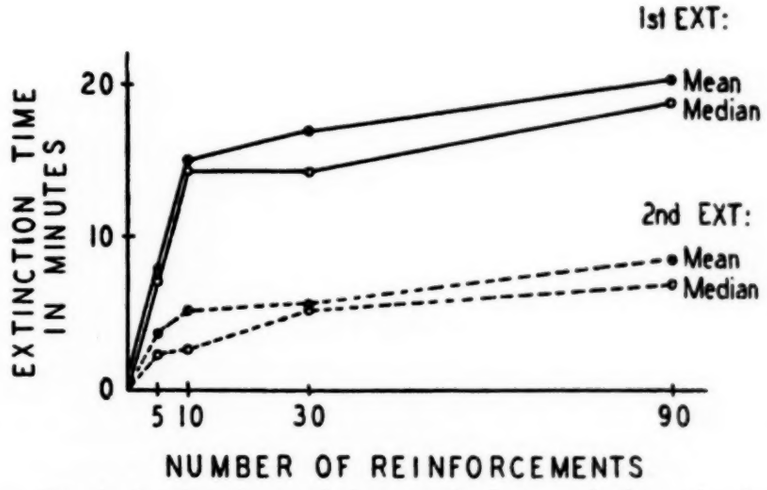

FIG. 4. Graph showing the total time required to reach the extinction criterion. The upper pair of curves is for the first extinction; the lower pair is for the second extinction, from which can be judged the amount of spontaneous recovery after one hour. Each point represents the central tendency of the scores from 35 animals.

mean extinction time scores. The slight reversal apparent in the median time curve cannot be considered a true reversal because of the very low reliability of the difference at that point (see Table 3).

Time and number of responses, although the best measures, are not identical. They can be more easily compared by reference to Fig. 5, in which they have been plotted against

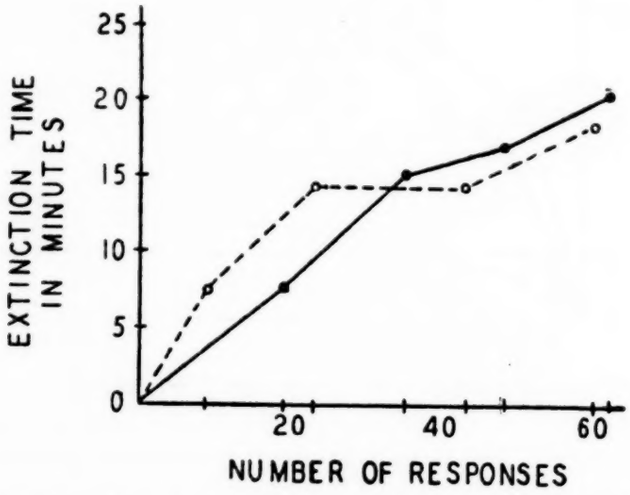

FIG. 5. Extinction time is here plotted against number of extinction responses for a comparison of the two functions. Means are graphed by the solid line, and medians, by the broken line. These are for first extinction only. The actual values are given in Table 2.

each other. The resulting curves reveal that the amount of time per response becomes less with more responses. Time is not a straight line function of the number of responses, as we would expect if the two measures were identical functions of the number of reinforcements. In agreement with Ellson (1), we are forced to regard them as separate functions of reinforcement.

Although rate of response was found to be a less reliable index of original reinforcement than the other measures, it is nevertheless roughly correlated with them. The greater the reinforcement and the greater the time and number of responses required to reach an extinction criterion, the smaller is the mean time between responses. Evidence for this is included in Table 2 and pictured in Fig. 6. From these and the critical ratios in Table 3 it is clear that rate of response

as a measure of amount of reinforcement is capable of reflecting only very gross differences. The only significant difference in rate is that between 5 and 90 reinforcements.

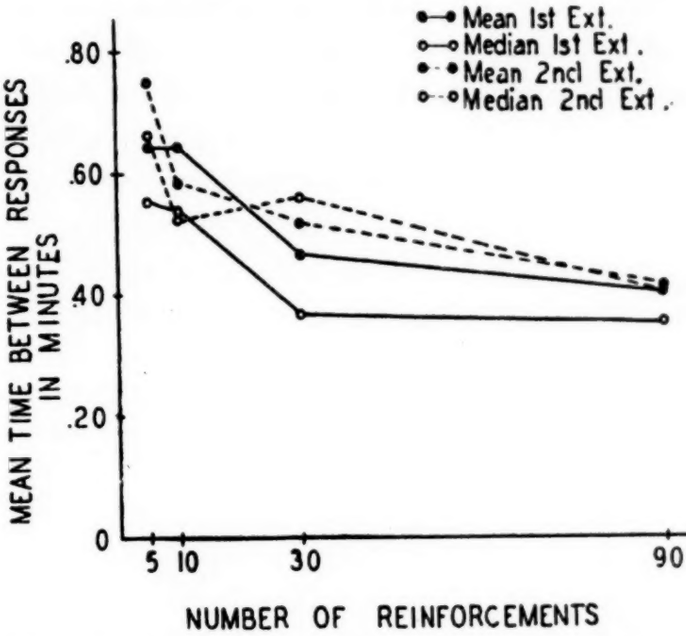

FIG. 6. The rate of response (mean time between responses) for both first and second extinction series, both mean and median measures. Actual values appear in Tables 2 and 4.

The obvious variability in rate of response, however, precludes any assumption of a constant rate uninfluenced by amount of reinforcement. It would be fair to conclude that rate of response is a reliable but crude measure.[3]

First Extinction. Theoretical Implications

In the extension of conditioned-response principles to the explanation of learning there arises the necessity for

[3] The experimental data were further examined to determine the effect of differential reinforcement on the *initial* rate of response. The mean inter-reaction time interval for the first five responses in the first extinction series was found to be .97, .93, .27, and .30 minutes for the 5, 10, 30, and 90 reinforcement groups respectively. Inasmuch as it is impossible to make this computation for the ten animals in the first group which made *no* responses (see Fig. 2), it was necessary in obtaining these values to exclude the ten extreme cases on each end of the distribution of the number of extinction responses of each group, leaving the middle 15 animals in each group. In only three of the cases which were finally included did the subjects make fewer than five responses. While the above results are not entirely consistent, there is a very definite suggestion of an inverse relationship between the strength of the habit tendencies involved, as indicated by the number of reinforcements, and the inter-reaction time interval at the beginning of experimental extinction.

precise quantitative determination of the postulated phenomena, as Hull (5) has emphasized. Without a quantitative expression of the relationship, for example, between amount of reinforcement and resistance to extinction, it would never be possible to predict with accuracy the effect of successive blocks of reinforcement on the strength of a habit. A simple 'more than . . . less than' statement is too general to be of use in the prediction of many particular instances. Taking the number of responses as the most reliable measure of resistance to extinction, the curves of both median and mean values obtained in this experiment have been smoothed in Fig. 7 by

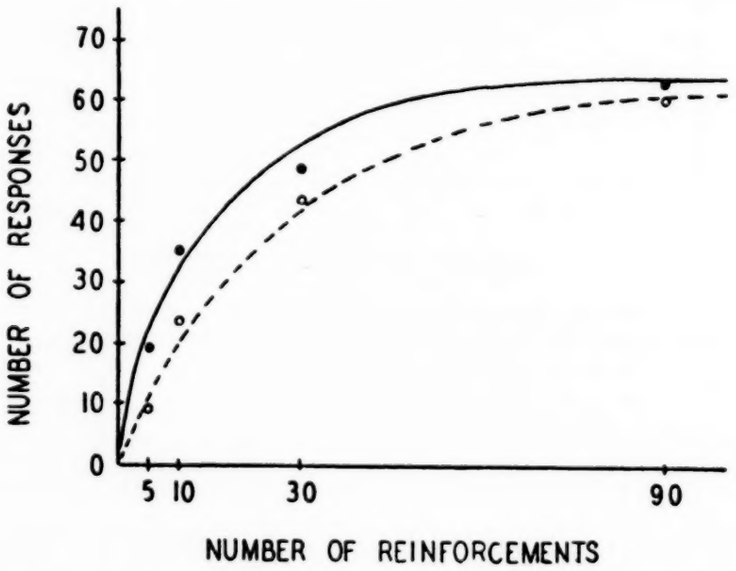

FIG. 7. Theoretical curves for mean and median values of the number of responses made in resistance to first extinction. The curves were fitted to the empirical data given in Table 2. The dots and circles are the empirical values for means and medians respectively. The mean curve, shown by the solid line, has the equation:

$$E = 64 - 64 \times 10^{-.05\,R^{.8}}.$$

The median curve, shown by the broken line, has the equation:

$$E = 62 - 62 \times 10^{-.017\,R}.$$

fitting to them theoretical curves. The equation found to fit best the mean values is:

$$E = 64 - 64 \times {}^{-.05R^{.8}}$$

where E is the number of extinction responses; R, the number of reinforcements; and 64, the value of an arbitrary limit. The corresponding equation for the median values is:

$$E = 62 - 62 \times {}^{-.017R}$$

By means of the above equations it is possible by interpolation and extrapolation to determine points in the relationship other than those empirically derived. The statistical reliability of the differences listed in Table 3 would indicate that interpolations made from the above equations would possess a fair degree of accuracy. Moreover, for reasons previously stated, it is likely that the more dependable equation is the one derived from the median values.

Second Extinction. Recovery after one hour

Spontaneous recovery in the strength of a bar-pressing habit after its extinction was demonstrated by Youtz (**11**) to be a real phenomenon, and the plotting of the curve of

TABLE 4

RESULTS OF SECOND EXTINCTION. SPONTANEOUS RECOVERY AFTER ONE HOUR

The percent of recovery is calculated from the total scores. Recovery measures are lacking on a few animals. The exact recovery interval was 65 minutes, including the previous 5-minute criterion for extinction.

Measure of Resistance to Extinction and Percent of Recovery		Group (Number of Reinforcements)			
		5 (N = 33)	10 (N = 34)	30 (N = 33)	90 (N = 34)
(*a*) Number of responses	Mean	6.7	10.4	12.3	19.8
	σ_m	1.4	2.1	1.7	2.8
	Median	3.0	7.0	11.0	11.0
	Percent recovery	35.	30.	25.	31.
(*b*) Time to reach criterion (minutes)	Mean	3.9	5.3	5.7	8.4
	σ_m	.8	.9	1.0	1.3
	Median	2.4	2.6	5.6	7.1
	Percent recovery	51.	36.	33.	41.
(*c*) Rate of response (in minutes)	Mean	.75	.58	.52	.41
	σ_m	.17	.13	.10	.07
	Median	.66	.53	.56	.40
	Percent recovery	117.	91.	111.	103.

recovery during time has just been completed by Ellson (**1**). In the latter work one of the recovery intervals tested was 65 minutes, the same interval used in the present experiment. In Ellson's study, 30 reinforcements were given; but since

these were complicated by training on another similar habit, the data from the two experiments cannot be directly compared. Ellson found 39 percent recovery in number of responses, 52.5 percent in time, and 157 percent in rate of response, though he concludes that the low reliability of the last measure makes its meaning very doubtful. The amount of recovery after the same interval for all reinforcement groups in the present study is presented in Table 4 and the statistical reliabilities of the recovery differences are given in Table 5. For the comparable 30-reinforcement group the

TABLE 5

RELIABILITIES OF MEASURES OF SECOND EXTINCTION

Critical ratios (Diff./σ diff.) of the mean differences between pairs of four reinforcement groups according to the three measures of resistance to extinction.

Paired Reinforcement Groups	Measures of Reinforcement		
	No. of Responses	Total Extinction Time	Rate of Response
5 vs. 10 reinf.	C.R. = 1.44	C.R. = 1.17	C.R. = 0.81
10 vs. 30 reinf.	= .70	= .29	= .38
30 vs. 90 reinf.	= 2.32	= 1.69	= .92
5 vs. 30 reinf.	= 2.55	= 1.38	= 1.15
10 vs. 90 reinf.	= 2.69	= 1.94	= 1.13
5 vs. 90 reinf.	= 4.18	= 3.00	= 1.89

percent of recovery is seen to be 25 percent for number of responses, 33 percent for time, and 111 percent for rate of response. The absolute amount of recovery is in all cases less than that obtained by Ellson. This is due, no doubt, to the fact that the strength of the one habit studied in the present experiment was not increased by generalized effects from a similar habit. The relative amounts of recovery for the three measures used, nevertheless, corroborate Ellson's results. In spite of the low statistical reliabilities of the differences between reinforcement groups in amount of recovery, resistance to second extinction is in the same direction as resistance to first extinction. That the amount of recovery is roughly proportional to the amount of original reinforcement is illustrated by the lower pairs of curves in Figs. 3 and 4.

For rate of response, all measures of recovery fluctuate around 100 percent, indicating that it is very little affected by a weakening of the habit. Properly speaking, the mean time between responses on the second extinction expressed as a ratio with the mean time in the first extinction is not really a measure of percent of recovery. In this case, percent of recovery would be more accurately expressed by a ratio between the speed of responding in the first few responses of the second extinction and the last few responses of the first extinction series. Nevertheless, the ratio used in Table 4 does indicate that the more reinforcements which have originally been given, the more the mean rate of response on the second extinction tends to approach the rate on the first extinction. Figure 6 affords a graphic comparison of the two.

Learning Time

The data were further analyzed to determine the average rate of responding during the course of learning. Records of the 35 animals receiving 90 reinforcements were measured for the amount of time required for each successive group of ten responses. The graph of the means is shown in Fig. 8. Less

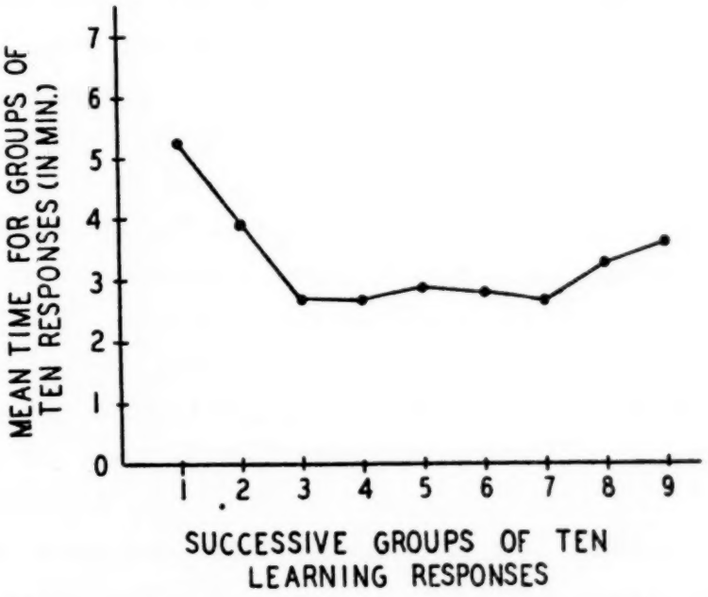

FIG. 8. The mean time required by 35 animals in the 90-reinforcement group to secure successive ninths of the 90-reinforcing pellets. All abscissa values represent means for successive groups of ten responses, with the exception of the first, which is based on only nine responses since the time elapsing between *no* response and the first response obviously could not be measured.

time is required for the second ten trials than the first ten, and after the second ten the rate of response becomes nearly constant except for a slight slowing up in the last twenty responses. This terminal increase in rate may be due to two factors: satiation and 'inhibition of reinforcement.' That partial satiation might be a factor is suggested by certain results of Skinner (**9**) showing a drop in acceleration beginning, in some animals, before the fiftieth response. Skinner attributes this to partial satiation. That satiation of hunger is not the only factor operative in the present experiment is substantiated by the fact that in some cases the rat's activities showed a marked change beginning at about the seventieth to eightieth response, consisting of agitated behavior (with complete disregard for pellets in the tray) strikingly similar to that displayed by the same rats during frustration (extinction). In lieu of a better explanation for this phenomenon, the author suggests it as a possible instance of 'inhibition of reinforcement' described by Hovland (**4**).

Summary

1. The behavior of 140 white rats was studied during the process of extinction of a bar-pressing habit which had been established by food-reinforcement to four different degrees of strength. Four groups of 35 rats each were given, 5 10, 30, and 90 reinforcements respectively, and twenty-two hours later were extinguished on the habit to a five-minute criterion. A second extinction series followed one hour after the first, constituting a test of spontaneous recovery. The chief aim of the investigation was to determine the quantitative relationship between resistance to extinction and amount of reinforcement. Three measures of resistance to extinction were used: the number of responses during extinction, total extinction time, and the mean time between extinction responses (rate of response).

2. Resistance to extinction increases with the number of reinforcements, by all measures used.

3. This increase has a negative acceleration, which is

described by two empirical equations based on the two most reliable measures.

4. Spontaneous recovery after one hour increases as the number of reinforcements increases.

5. This increase is also negatively accelerated, though the curve is much less steep than that for first extinction.

6. The extent of recovery after one hour is 25 percent to 35 percent in number of responses, and 36 percent to 51 percent in total time. Rate of response is slower in a habit already weakened by extinction; although with increasing amounts of reinforcement the rate of response on the second extinction approaches the rate on the first extinction.

7. According to their effectiveness in differentiating the amount of reinforcement, the measures of resistance to extinction rank in the following order: number of responses in extinction, total extinction time, and rate of response.

8. The course of learning (reinforcement series) is characterized by an initial acceleration in speed of responding which levels off to a fairly constant rate until the last twenty responses, at which point a marked decrement in speed sometimes appears. It is suggested that this decrement is in part due to partial satiation of the hunger drive and in part due to 'inhibition of reinforcement.'

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VISUAL AND VOCAL RECOGNITION MEMORY *

BY HILDING B. CARLSON AND HARVEY A. CARR

For over a quarter of a century, numerous experiments have been made comparing memory efficiency of the different senses—vision, audition, kinæsthesis, etc. No consistent group differences have been found. Some of the possible causes of the contradictory findings have been enumerated by Koch (2) to be (1) the different measures of learning efficiency used, (2) the stage in the learning process at which measurement is made, (3) the nature of the recording response, and (4) the degree of familiarity with the experimental methods used. It is also possible that vision is relatively superior for some individuals and vocality for others and that the two cancel each other for the group as a whole. If it is possible to isolate such individuals, we may then have a further explanation for some of the discrepancies previously reported. This study proposes to do this. The term vocal is used to refer to the kinæsthetic and auditory cues that result if an individual pronounces a word, even though inaudibly, inasmuch as there is no adequate means of differentiating them in this circumstance.

One way of attempting to isolate those individuals in whom vision is relatively superior and others in whom vocality is relatively superior, would be to vary the character of the material to be memorized. In a previous study of memory (1), in which this was done, considerable data were collected, a portion of which is admirably suited for the purpose of this study and has been used in the present analysis. Those aspects of the earlier study which are essential to an understanding of the results reported in the present study are given here.

While various kinds of material to be memorized might have been utilized, words were used since they are much better especially for presentation. Their use necessi-

* From the Psychological Laboratory of The University of Chicago.

tated employing the recognition method of testing memory, which in turn meant that specific distractors had to be used in order to obtain differentiation. Accordingly, recognition lists were made, systematically varying the distractors in visual appearance, vocality, and in their combination. For this purpose, groups of words were selected of such character that other words could be found that have particular relationships to the first word. One group of words was selected because for each word another word, alike in meaning, but differing in visual appearance and vocality, could be found; another group of words was selected because for each word another word differing only in visual appearance could be found; a third group of words was chosen because for each word another word could be found which differed only in vocality. These groups are E, F, and C of the previously reported study and the same letters will be used to designate them here. Examples of these words are included in Table I.

One word of each pair was included in an exposure list. Both words of the pair were included in a recognition list, the word not used in the exposure list serving as a distractor for the other. The relation between the associated words in a recognition list was constant, so that the use of a particular mode or the combination of modes was favored.

TABLE I

RELATION BETWEEN THE WORDS OF A PAIR IN THE EXPOSURE AND RECOGNITION LISTS

Group	Number Words in Each Recognition List	Words Alike in Respect to:	Words Different in Respect to:	Example
E	44	Vocality Meaning	Visual appearance	through thru
F	26	Visual appearance Meaning	Vocality	con'tem-plate con-tem'plate
C	48	Meaning	Visual appearance Vocality	rely depend

Inspection of this table shows that while meaning, vision, and vocality could have been used in memorizing the words in the exposure lists, the subjects could not use meaning to distinguish between the words of a pair in the recognition lists, but could use visual appearance in series E, vocality in series F, and visual appearance and vocality in series C. What we wish to do in this study is to find those subjects who consistently have relatively superior scores in one series as compared with another series. If such subjects can be found, we thereby demonstrate that there are individual differences in ability to utilize visual and vocal cues in recognizing words, and from this, that the ability to memorize words involves a visual and a vocal component.

Rather than rely upon a single index of ability to use visual and vocal cues in memorizing and recognizing words, as has been done by most of the previous experimenters, five parallel forms were made for each modality and for their combination. There were thus fifteen tests in all.

To make it possible to give the experiment to a group of subjects at one time and to control the exposure time for each word, the words were serially exposed on a screen by means of a film and a projection machine.

The exposure list was presented to the subjects. They were told that a series of words would be shown on the screen and were instructed to memorize the words so as to be able to recognize them when presented as part of a longer list. No instructions as to the mode of memorizing were given. The list was presented but once. Each word was exposed for two seconds.

The recognition list was shown immediately after the exposure list. The subjects were told that all the words in the first (exposure) list were in the second (recognition) list, interspersed with other words. Nothing was said concerning the nature of the distractors. No mention was made that the recognition list was twice as long as the exposure list. The subjects were asked to indicate on a prepared data sheet which words were in the exposure list and which were not. They were told to guess whenever in doubt. Thus a response was made to every word in the recognition list. This list was also exposed but once. The exposure time for each word was three seconds, one second longer than in the exposure list, to permit the subject time to mark a check on the data sheet.

A total of 202 high school and college subjects completed the experiment.

As the majority of the subjects were not familiar with the experimental set-up, five preliminary practice lists with nonrelated confusion words were given in order to prevent as much as possible the variability in the scores that might result from this lack of familiarity with the testing procedure. No use was made of these data.

To increase further the reliability of the tests as indices of the ability of the subjects to memorize and recognize words, the experiment was repeated after an interval of two to three months. The average score of the two presentations was then taken as an approximation of the true score.

Since the mean and standard deviation of the average scores of the tests differed, no direct comparison could be made between an individual's average scores on the tests in one series and those in another. Comparable scores had to be used. Accordingly, the individual's average scores on each of the tests were transmuted into normalized standard scores.

When this had been done, the results for each of the subjects were studied in order to select all those whose scores are higher on the tests in one series than in another. After some study, it was decided to select those subjects whose scores were higher on at least four of the five parallel tests in one series than on four or five in another series. This method has the advantage over other arbitrary methods in that it selects only those individuals whose scores are fairly constant within a series and whose differences in response to one series as compared with another exhibit considerable degree of statistical significance.

In order to illustrate this basis of selecting these subjects, an example is given in Table II for subject number 32. This table shows that the scores on each of the five parallel forms are higher in series E than any in series F. The scores for most subjects selected, of course, are not as consistent as this.

TABLE II

EXAMPLE SHOWING CONSISTENTLY HIGHER SCORES IN SERIES E THAN IN SERIES F

Subject Number	Series	Test Number				
		1	2	3	4	5
32	E	1.73	1.04	0.97	1.91	1.01
	F	0.09	0.73	0.06	0.66	0.06

The number of subjects who made consistently higher scores on the tests in one series as compared with those in another series is included in Table III. To give some idea of the size of the differences between the scores on the parallel forms in each series for each group of subjects selected, the mean scores have been calculated and are indicated in this table.

TABLE III

MEAN SCORES OF SUBJECTS CONSISTENTLY SUPERIOR IN ONE SERIES AS COMPARED WITH ANOTHER

Group	No. of Subjects	Comparison		Mean Score on Each Test				
				1	2	3	4	5
1	38	E higher than F	E	.58	.60	.57	.67	.53
			F	−.10	−.30	−.44	−.44	−.45
3	42	F higher than E	F	.27	.20	.40	.39	.31
			E	−.45	−.56	−.48	−.39	−.56
4	39	E higher than C	E	.36	.37	.40	.28	.26
			C	−.50	−.36	−.50	−.52	−.46
6	40	C higher than E	C	.47	.33	.62	.52	.49
			E	−.26	−.41	−.25	−.21	−.28
7	44	F higher than C	F	.58	.42	.64	.50	.53
			C	−.53	−.40	−.43	−.38	−.42
9	48	C higher than F	C	.70	.58	.61	.59	.68
			F	−.35	−.36	−.34	−.22	−.47

Let us consider first the subjects in Group 1. The scores for these subjects are consistently higher on the tests in series E than on those in series F. In both series there are visual differences between the related words. In series E the

paired words differ only in spelling, so that there is little or no possibility for a subject to differentiate between them by the use of vocal cues; while in series F, the paired words differ only in syllabication and in position of the accent marks, so that a subject would be aided in his attempt to distinguish between them if he used vocal cues. Since these subjects were superior in series E as compared with series F, it would appear that relative to the entire group, these subjects were better able to make use of visual cues alone than they were able to make use of the visual cues that could be converted into differentiable vocal cues. In other words, we might say that these subjects used vision primarily rather than vocality, in their attempt to memorize the words. The subjects in Group 3, on the other hand, were better able to make use of the visual cues that can be converted into differentiable vocal cues than they were able to make use of visual cues alone. That is, they tended to use vocal cues rather than visual cues alone.

Let us consider next the thirty-nine subjects in Group 4 who were consistently superior in series E as compared with series C. Vision alone could be used in series E while vision and vocality could be used in series C. These subjects were relatively more adept with the use of vision alone, than they were with the combination of vision and vocality. On the other hand, the subjects in Group 6, having consistently higher scores in series C than in series E, were relatively more capable of using the combination of vision and vocality than they were of using vision alone.

In Group 7, the subjects excelled in series F as compared with series C. While the paired words in both series differ in visual appearance and in vocality, in series F the visual differences are limited to differences in syllabication and in position of the accent mark, and so give less marked visual cues than do the visual differences in series C. Vision alone then is not very helpful in discriminating between the words of a pair in series F, but neither is vocality, unless these visual cues are used by the subjects as aids in the pronunciation of the words, in which case vocality may become of considerable

aid. The subjects in this group then would appear to have relied primarily upon vocality rather than vision in memorizing the stimulus words as contrasted with vision and vocality jointly. The subjects in Group 9, on the other hand, having consistently higher scores in series C than in series F apparently did not rely upon vocality primarily but rather upon a combination of vision and vocality.

There are, however, other explanations for the results. If we knew all the subjects in the experiment were able to use the visual cues in each series with equal facility, we could be more certain that the differences found have been correctly interpreted. But it is quite possible that the subjects differ in their ability to use different kinds of visual cues. If so, this would account for the differences found in these groups of subjects. An alternative explanation for the results obtained, then, is that the subjects in each group excelled in an ability to use a specific visual form or pattern as contrasted with another specific visual form or pattern ability. If this is the case, it would be necessary to postulate that there are a number of fundamentally different visual characteristics involved in the recognition of words having those aspects included in this experiment, each characteristic demanding a specific visual ability. Whether such specific visual abilities exist, their number, and their nature, cannot, of course, be answered by this experiment.

There is another possible explanation for the results when series C is involved. In this series, while the related words are synonymous, there is nevertheless some shade of difference in their meaning, and it is possible that a number of words in the exposure list have other more familiar associations for these subjects than have the synonymous distractor word used. If this is the case, meaning might have been used to advantage, introducing a logical factor which this experiment attempted to exclude.

It would be scientifically more satisfying if these interpretations could be checked empirically. Fortunately, it is possible to do this, since a considerable number of subjects appear in more than one group. If our first interpretation is

correct, several of the groups must logically contain the same subjects. Accordingly, further study of the data was made in order to determine the extent to which any two groups are composed of the same subjects. Table IV is the result.

TABLE IV

EXTENT TO WHICH TWO GROUPS ARE COMPOSED OF THE SAME SUBJECTS

Group		$E \overset{1}{<} F$	$E \overset{2}{=} F$	$F \overset{3}{<} E$	*n*	$E \overset{4}{<} C$	$E \overset{5}{=} C$	$C \overset{6}{<} E$	*n*
4	E<C	13	19	7	39				
5	E=C	19	82	22	123				
6	C<E	6	21	13	40				
	n	38	122	42	202				
7	F<C	5	20	19	44	22	20	2	44
8	F=C	12	77	21	110	17	79	14	110
9	C<F	21	25	2	48	0	24	24	48
	n	38	122	42	202	39	123	40	202

A cursory inspection of this table indicates at once that there are definite trends present. In general, if an individual has consistently higher (or lower) scores on one series as compared with a second series, he is much more likely to have higher (or lower) scores on the first as compared with the third than vice versa. Further discussion, therefore, will be limited to a consideration of those individuals who have consistently higher (or lower) scores on one series as compared with the two remaining series. These individuals are included in Table V.

TABLE V

NUMBER OF SUBJECTS WHO HAVE CONSISTENTLY HIGHER (OR LOWER) SCORES IN ONE SERIES AS COMPARED WITH THE OTHER TWO SERIES

Groups	Comparison		*n*	Interpretation. Subjects relatively superior in the use of
1 and 4.....	E<F	E<C	13	Vision
1 and 9.....	E<F	C<F	21	Vision
3 and 7.....	F<E	F<C	19	Vocality
3 and 6.....	F<E	C<E	13	Vocality
4 and 7.....	E<C	F<C	22	Either vision or vocality alone
6 and 9.....	C<E	C<F	24	Vision and vocality together

The subjects common to groups 1 and 4 and 1 and 9 apparently are superior in vision, while those in 3 and 7 and 3 and 6 are superior in vocality. In both cases, the two groups differ in respect to that to which they are superior. The subjects in these groups use one cue better than another. In groups 4 and 7, the presence of two cues is apparently distracting, for the subjects use either one alone better than the two together. In groups 6 and 9, the subjects use two cues to better advantage than either one alone. Since the interpretation of the results is of the same nature as that first made, the alternative explanations apparently need not be considered and little further comment is needed. It is of interest to add, however, that among the subjects who have consistent differences in their scores on one series as compared with the other two series, the two largest groups show relative superiority and inferiority in the use of the combination of vision and vocality, the next two groups in the use of vocality alone, and the two smallest groups in the utilization of vision alone.

To sum up briefly, series of visual recognition tests of words favoring the use of vision alone, vocality alone, and vision and vocality combined, were given to 202 subjects. A considerable number of subjects were found to be consistently superior in one series, as contrasted with another. The explanation advanced is that these subjects differ in their ability to use visual, vocal, and visual-vocal cues. It follows then that some of the conflicting reports previously made comparing memory efficiency of the different senses may be due in part to differences in the abilities of the subjects comprising the groups involved.

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ELECTRICAL RESPONSES FROM THE COCHLEA OF THE FETAL GUINEA PIG

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In the course of certain preliminary experiments (conducted in the Laboratory of Psychology at the University of Rochester) designed to test the feasibility of a study of the origin of the cochlear effect by correlating the histological appearance of the fetal ear with the magnitude of the electrical phenomenon in question, we have made a brief study of the electrical and behavioral responses of the guinea-pig fetus to pure tone air-borne stimuli. This work, though of a character preliminary to the fuller investigations of these effects now contemplated, has, we believe, yielded results of sufficient interest to warrant their reporting in the present note.

McCrady, Wever and Bray [1] have given the results of an investigation of the electrical response from the cochlea of the post-natal pouch young opossum (*Didelphys marsupialis*) between the ages of 59 and 82 days after birth. Though a correlative study of development of function, of character similar to that now contemplated by ourselves, could no doubt be effected using this animal, the fact that a great majority of the electrical studies of hearing in adult animals have been carried out on the guinea-pig has persuaded us, in the interests of continuity, of the desirability of employing the guinea-pig fetus for our present purpose. Additionally we may note certain other practical and physiological differences between the pouch young and the fetal mammal which at least justify a study of both forms.

Using an operative technique previously described,[2] a

[1] McCrady, E., Jr., Wever, E. G. and Bray, C. W. *J. Exp. Zool.*, 1937, 75, 503–517.

[2] Carmichael, L., *Gen. Psych. Monog.*, 337, 16, 1934.

series of fetal guinea pigs of differing post-insemination ages was exposed for study with placental circulation and most other pre-natal conditions normally maintained. Exposure of the fetal middle ear cavity may be effected by a technique virtually identical with that employed for adult animals,[3] and this we need not describe in detail here. In view, however, of the difficulty of ligaturing blood-vessels necessarily requiring section for this exposure, owing to the somewhat reduced scale of the operation, we have preferred, to the use of scalpel and scissors, the employment of a conventional electric cautery maintained at high temperature. In this way hemorrhage into the middle ear cavity may with care be completely avoided, and the advantage of this in preserving satisfactory electrical conditions subsequently requires no stressing. A further advantage of the use of the cautery lies in the fact that the time ordinarily required for such a middle ear exposure may be shortened very greatly.

With the completion of this operation the fetus was clamped in a specially carved wooden holder so constructed that the umbilical cord was not under tension. The maternal and fetal organisms were then partly immersed in a bath of physiological saline at approximately blood temperature (37.5° C.). In this holder the head of the fetus was firmly supported so that the region of the incision was just above the level of the liquid. A suitably insulated, ball-tipped silver wire electrode, in a flexible holder, was then manipulated into position such that it was in light but firm contact with the external surface of the bone at the base of the exposed cochlea; in the fetal animal this bone is more fragile than in the adult. A second electrode was attached to the retracted skin at the locus of the incision. The two electrodes were connected to a resistance-capacity coupled amplifier, the first stage of which was such as to permit the employment of an input circuit neither side of which was grounded. The output of this terminated in a Westinghouse Type PA (moving-mirror) oscillograph, from which photographic records could be secured by a moving sensitized-paper camera. A pair of

[3] *E.g.*, HALLPIKE, C. S. and A. F. RAWDON-SMITH, *J. Physiol.*, 1934, **81**, 395.

telephones additionally made the amplified potentials audible.

The youngest fetus from which a cochlear electrical response was secured in this study was 52 post-insemination (hereafter referred to as p.i.) days of age. Two much younger fetal litters were exposed, but were found to be unsuited for the experiment in its present, preliminary form. It may be pointed out, however, that we have little doubt that fetal guinea pigs younger than 52 p.i. days will give a cochlear electrical response, though we have not thus far had an opportunity to study such preparations. Five older fetal litters were also exposed. Three of these, in age approximately 58, 62, and 62 p.i. days, yielded preparations from which an electrical response was successfully obtained. These electrical responses may be described, in approximate figures, as follows:

In the 52 p.i.-day fetus a small response (1–2 μV peak) was obtained to a stimulus of frequency 600 c.p.s., and intensity 100 db. above the human threshold at the animal's ear. Declining responses were obtained to tones below this, and above 2000 c.p.s. This fetus also reacted overtly to auditory stimuli, this being the earliest age at which such a response has ever been observed.[4] The greatest electrical response photographically recorded amounted to 100 μV peak, from a fetus of approximately 62 p.i. days of age, though responses in excess of this were observed. A fetus from the other litter of the same age gave responses of the same order, and a record from this is shown in Fig. 1. Both the latter animals showed 'startle' responses to intense stimuli. Though all electrical responses reported may appear somewhat small in comparison with those conventionally obtainable from the adult animal, this may be ascribed, in the first place, to the fact that the external auditory canal in the fetus is not unobstructed, and in consequence the stimulus is much attenuated before reaching the cochlea. In the second place, we may point out that the younger fetus gave a smaller response than the older ones, from which we may tentatively deduce a progressive development of the auditory mechanism, as would be supposed.

[4] CARMICHAEL, *op. cit.*

FIG. 1. Oscillogram showing electrical response from cochlea of fetal guinea pig, age 62 p.i. days. Record reads from left to right. Descent of the time line indicates onset of sound stimulus, ascent signifies end. Time interval marked = 0.1 sec., calibration indicates 50 μV. Frequency of stimulus 320 c.p.s., intensity approximately 100 db. above the normal human threshold.

We must emphasize, however, that quantitative conclusions of this type are scarcely justified from the data gathered thus far. The purpose of this brief account is rather to indicate the feasibility of the techniques employed, and the presence, at least in the older fetal guinea pig, of electrically functional intra-cochlear structures.

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ON THE DISCRIMINATION OF MINIMAL DIFFERENCES IN WEIGHT: IV. KINESTHETIC ADAPTATION FOR EXPOSURE-INTENSITY AS VARIANT

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According to the principle of neural availability, differential sensitivity ($= 1/\Delta I$) is assumed to be an increasing function of the number of neurophysiological elements (= number of nerve impulses per unit time) available at any instant for the discrimination of a just noticeable difference in subjective intensity (**6**). Differential sensitivity is thus regarded as a direct measure, not of the neural excitation itself, but of its *complement*, *i.e.*, of the excitation potentially available for the discrimination at the time the judgment is made. The relation which has been postulated to exist between excitation and its complement may be expressed in the form of a rational equation:

$$N_e + N_a = N_t, \qquad [A]$$

where N_t is the total amount of excitation per unit time initially available under the physical and psychophysiological conditions of the experiment; and where N_e is the amount of excitation per unit time aroused by stimulation under specified conditions. N_a is accordingly the amount of excitation per unit time potentially available during the moment the discrimination in question takes place. Equation [*A*] is purely neurophysiological in conception.

The principle underlying this equation has been generalized to account neurophysiologically for sensitivity data from most departments of sense (**6, 9, 12, 20**). It has also been employed to provide theoretical orientation as regards the

design and control of experiments in modalities which have not yet been systematically studied in thoroughgoing fashion (**7**, **8**, **10**, **11**, **13**). In the field of kinesthesis, the theory definitely implies that bimanual differential sensitivity must be greater than unimanual differential sensitivity for comparable data when the stimulating intensity is constant. Clearly, under such circumstances, N_t and N_e for bimanual presentation must respectively exceed N_t and N_e for unimanual presentation. It follows at once from Equation [*A*] that N_a for the former must exceed N_a for the latter set of conditions. If differential sensitivity does in reality vary directly with N_a, then bimanual must be greater than unimanual differential sensitivity. This requirement has been investigated and was found to be substantiated by experimental fact (**10**).

Another consequence which is also subject to direct experimental test can be derived from a consideration of the neurophysiological finding of Field and Brücke. These workers have determined under specified conditions the manner in which the refractory period of nerve (*a*) increases during intermittent stimulation and then (*b*) recovers (decreases) after the cessation of exposure (**4**). Stimulation was continued for as long as 10 minutes. In general, the refractory period was found to increase continuously during stimulation;—the rate of increase conforming to a law of diminishing returns. Following cessation of the stimulus, the refractory period was observed to decrease (continuously approaching its normal value) in a manner which can be described by an exponential function. Thus the excitation per unit time produced by direct electrical activation of nerve (*i.e.*, without the mediation of sense organ activities) decreases during continued intermittent stimulation. Immediately following this stimulation, the refractory period returns to its nominal pre-exposure value; hence, more and more excitation becomes available for a given amount of the stimulus during recovery.

This neurophysiological finding possesses special significance for the interpretation of measured variations in sensory threshold-stimuli and differential sensitivity. It possesses ad-

ditional interest because it serves to provide us with a factual basis for a neurophysiological explanation of the phenomenon generically called 'adaptation.'

Taken in conjunction with the availability principle, this experimentally established fact has definite implications for kinesthetic as well as for all other types of sensory adaptation. When a heavy weight is lifted and sustained over a sufficient period of time, for example, the refractory periods of the nerve fibers involved may be expected to increase. N_t should then *decrease*. Moreover, in keeping with the results furnished by Field and Brücke, N_t may be expected to *increase* during the interval of time required for the individual fibers to recover, *i.e.*, to reach their preëxposure (or 'normal') condition. The total amount of excitation ($= N_t$) available for stimulation must accordingly be less at the end of the exposure than it was immediately before the exposure.

When nerve fibers are in the quiescent state, there is of course no excitation, and $N_e = 0$. Equation [*A*] then reduces to $N_a = N_t$. For this condition, the absolute threshold-stimulus ($= \Delta W_0$) may be expected to decrease during recovery (1): [$1/\Delta W_0$ should increase]. The outcome is similar when N_e is greater than 'zero.' According to the availability principle, differential sensitivity ($= 1/\Delta W$) for given values of the standard weight W may likewise be expected to increase during the recovery interval following exposure to a heavy stimulus. The purpose of the experiment reported in this paper is to validate this theoretical consequence and to determine specific properties of the function relating $1/\Delta W$ and recovery-time.

Apparatus, Method and General Procedure.—To determine the general nature of the relationship between differential sensitivity and recovery-time, three different exposure-intensities (500, 1200 and 4000 grm.) were lifted with the right hand and sustained for a period of one minute(= exposure-time). Immediately following the exposure ($= W \times t$), differential sensitivity was measured at various time-intervals until the value of ΔW had reached its normal magnitude as measured just before exposure. All measurements were made by the method of limits (continuous increase at a constant rate).

The essential elements of the apparatus have previously been described in detail (8). The observer's right arm was relaxed on a horizontal platform elevated to the height of his arm-pits. The arm was flexed about 90 degrees at the elbow. The exposure-weights and the standard weights were lifted from the wrist as fulcrum and

were sustained in essentially the same manner at a height of approximately 2.5 cm. A passive procedure was used. The standard (= W) weighed 200 grams. At intervals during the recovery-period, this weight was increased at a constant rate (= 10 grm./sec.) by adding mercury from a calibrated burette until the observer signified an increase in the subjective effect (= kinesthetic intensity, *cf.* **8**, p. 316). Readings were taken as nearly as may be at 0.25 min. intervals.

All ΔW-values were measured in grams. In reality, they are properly to be expressed in relative *energy* units. However, since the time required for the delivery of a given amount of mercury in these experiments is directly proportional to ΔW itself, it can have no effect upon the final result if we express our data in units of log-weight. The form of the functions sought will not be varied at all, provided of course that log-units are employed. Mathematically, log ΔW is linearly related to log Δ-energy for these experiments. For this reason, our measurements have been presented in terms of log$-\Delta W$.

Results.—Complete sets of measurements were secured from each of two observers (A.H.H. and M.J.Z.) for all three exposure-intensities. The data are given in Table I. The

TABLE I

LOG ΔW-VALUES FOR EACH OF TWO OBSERVERS DURING POST-EXPOSURE TIME

The exposure-intensities were 500, 1200 and 4000 grm.; the exposure-time was constant (= 60 secs.). Each ΔW-value was measured at W = 200 grm.

Time, in secs.	Observers					
	A.H.H.			M.J.Z.		
	log ΔW for Exp.-W. =500 grm.	log ΔW for Exp.-W. =1200 grm.	log ΔW for Exp.-W. =4000 grm.	log ΔW for Exp.-W. =500 grm.	log ΔW for Exp.-W. =1200 grm.	log ΔW for Exp.-W. =4000 grm.
30	1.781	1.982	2.208	1.785	2.081	
45	1.686			1.682		2.250
60	1.630	1.821	2.030	1.650	1.902	
75				1.650		
90	1.600	1.763	1.945	1.575	1.791	2.002
105		1.720			1.819	
120	1.575	1.720	1.841	1.575	1.785	1.875
135					1.688	
150	1.570	1.632	1.768	1.536		1.780
165					1.689	
180	1.535	1.618	1.742			1.820
200					1.649	
210						1.770
215			1.669			
230					1.600	
240		1.551				
250						1.633
270			1.631		1.575	
300						1.610
315			1.600			
330			1.551			1.608
360			1.577			
390						1.631
420						1.572

ΔW-values are expressed in grams; post-exposure times, in secs. Log ΔW is in every instance linearly related to log (Δ-energy). The data are also shown graphically in Fig. 1. The uppermost functions are based on data secured from A.H.H.; the lower graphs, on data from M.J.Z.

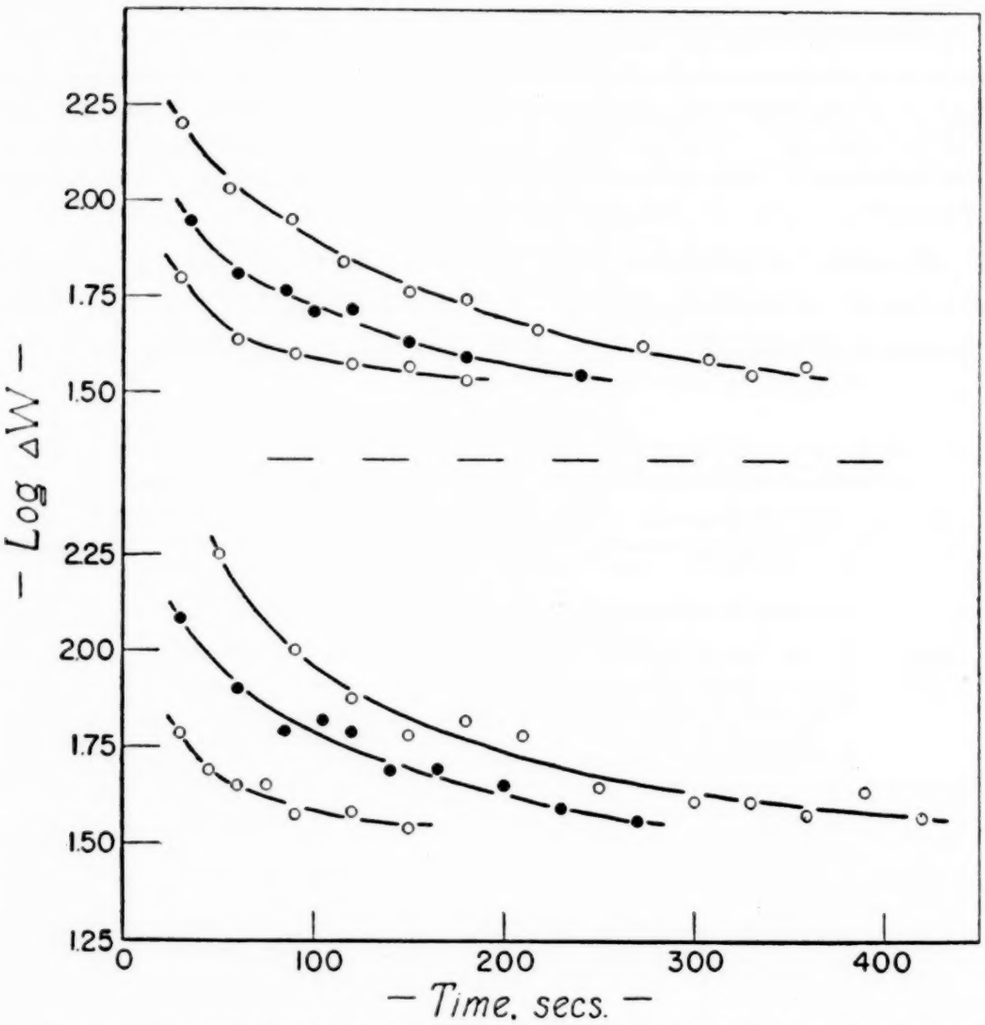

FIG. 1. Typical functions showing the behavior of log ΔW for each of two observers during *recovery-time* following stimulation by exposure-intensities (W = 500, 1200 and 4000 grm.). Exposure-time was constant (= 60 secs.). In each case, log ΔW decreases during the post-exposure interval and approximates its normal preëxposure value. At any moment during recovery, log ΔW is an increasing function of the exposure-intensity. The duration of the total recovery period also varies directly with the exposure. For a neurophysiological explanation of these results, see text.

These measurements bring to light three major points of fact. In the first place, log ΔW, and therefore log (Δ-energy), decreases continuously as a function of post-exposure *time*

for each observer. This statement is independent of the exposure-intensities employed. Secondly, at any given moment during the recovery interval, log ΔW is for each observer an increasing function of the exposure-intensity. Finally, the duration of the total recovery-period varies directly with the exposure-intensity. These three facts may be accepted as established by the results obtained in the present experiment.

Our determination of the form of the functions drawn in Fig. 1, however, rests on a more tenuous foundation. Several different equations can be fitted to the data, and only a method like least squares can provide a suitably unique criterion for a final selection among them. We have not adopted the least squares criterion—even though it could be done nicely for the data presented in Table I (*cf.* **2**). Instead, we have been satisfied simply to examine a number of other functions (obtained for the same observers under essentially identical conditions) also, and to estimate by visual comparison the modal form (*i.e.*, the most probable shape) of these functions without reference to specific constants. The curves drawn in Fig. 1 have been determined in this manner.

Interpretation

On the basis of the availability principle and the constant quantity hypothesis, these results can be accounted for simply in terms which are wholly consonant with experimentally established neurophysiological fact.

During exposure, the refractory periods of the involved nerve fibers may be assumed to increase by an amount which varies directly with the exposure ($= W \times t$). This is consistent with two facts established experimentally by Adrian: (*a*) for continued stimulation, the frequency of the impulses in a single nerve fiber decreases as a function of time during exposure; and (*b*) the frequency at any given moment during exposure is an inverse function of the stimulus-amount (**1**). This assumption is also consistent with the similar fact established for direct electrical stimulation of nerve by Field and Brücke (**4**).

Now, if the perception of a just noticeable increment in kinesthetic intensity is contingent upon the eventuation in the central nervous system of a constant increase in the number of impulses per unit time (constant quantity hypothesis), it then follows from the availability principle that ΔW should be greater just after exposure than just before—a fact demonstrated by the data secured in the present experiment.

The results of Field and Brücke can likewise be employed to account for the increase in differential sensitivity during the post-exposure interval. Log $(1/\Delta W)$ increased with an increase in post-exposure time because the refractory periods of the involved nerve fibers decreased during this interval. At any instant during the recovery interval, log $(1/\Delta W)$ varied inversely with exposure-values;—the refractory periods increased with stimulus-amount. Finally, the total recovery-time was longest for the strongest exposures, because the refractory periods of exposed nerve fibers require more time to recover from strong exposures.

In this way can one provide a theoretical basis for expecting the results obtained in the present experiment solely in terms that are consistent with experimentally established facts—facts concerning the activities of individual nerve fibers.[1]

On the other hand, we have by no means provided a *complete* explanation for our results. Successive effects occur, and factors which are not neurophysiological are also involved. Brücke, for instance, has shown conclusively that the refractory periods of individual muscle-fibers during adaptation can function in a manner quite similar to nerve (*cf.* also, **17**). Part of the process responsible for the behavior of ΔW during recovery may definitely be localized in muscle-fibers.

[1] Clearly, this basis can be applied to sensitivity data obtained during the course of adaptation in *any* department of sense. For visual dark adaptation (monocular and binocular), *cf.* H. Piper (**18**); for audition, see A.F. Rawdon-Smith (**19**) and A. H. Holway, R. C. Staton and M. J. Zigler (**12**); for taste, H. Hahn (**5**); and for smell, H. Zwaardemaker (**21**).

Other interpretations are also available: *cf.*, *e.g.*, G. T. Fechner (**3**), C. S. Myers (**15**, p. 207ff), R. Matthaei (**16**). These interpretations, however, are sheerly descriptive in character. They either re-describe or summarize the data. They do not explain them.

Moreover, as is frequently argued, residual effects (*cf.* after-discharge) can take place at various inter-neural junctions, and thus the effect may also depend on factors other than those localized either in nerves or in sense organs *per se*. Sense organ and synaptic processes, however, are seldom neglected in the interpretation of sensory functions. We would therefore emphasize the fact that one can provide (if not a complete) at least a *sufficient* basis for expecting the results secured in the present experiment solely in neurophysiological terms.

Summary

Immediately following exposure ($= W \times t$), kinesthetic differential sensitivity ($= 1/\Delta W$) was measured for specified conditions as a function of post-exposure time (t, in secs.). The exposure-intensities were 500, 1200 and 4000 grams; the exposure-time was constant ($= 60$ sec.). All measurements were made by way of the method of limits for a standard weight of 200 grams.

Three principal facts were established by the measurements. For each of two practised observers, differential sensitivity as a function of post-exposure time was found to increase continuously until it approximated its normal (pre-ëxposure) value. At any given moment during the recovery interval, differential sensitivity varied inversely with the exposure-intensity. The duration of the total recovery-period varied directly with the exposure-intensity.

On the basis of the principle of neural availability and the constant quantity hypothesis, it was shown that these facts can be accounted for simply in terms which are wholly consistent with experimentally established neurophysiological fact.

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THE RELATION OF TIME ESTIMATION TO CERTAIN PHYSIOLOGICAL CHANGES

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Many different psychological problems relating to the subject of time have been investigated.[1] Among the earlier studies were several dealing with the Weber-Fechner Law,[2] comparison of filled versus empty time [3] and a comparison of time in passing with time in retrospect.[4] The more modern studies have dealt with such topics as methods of time estimation,[5] individual differences in estimation,[6] the relation of time to rhythm,[7] and the development of time concepts in children.[8] A series of studies has also been devoted to certain physiological processes in relation to time estimation. Among these are studies of breathing and muscle strain,[9] time judgment and sleep, [10, 11] the effect of illness, the relation of

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circulation,[12, 13] chemical and temperature effects,[14, 15, 16] and basal metabolism [17] to time estimation.

The chief characteristics of these latter studies seem to be a lack of consistency and even of disagreement in the results. Despite this fact there is a widespread idea that estimations of short time intervals are based upon certain bodily changes such as breathing, blood pressure changes or heart beat.

The present study was designed to investigate this hypothesis, that is, it is an attempt to determine a physical basis for the estimation of short time intervals. The physiological processes which were selected for study were (1) pulse rate, (2) heart work, (3) breathing rate, (4) breathing work and (5) blood pressure changes. Subjects were given time intervals from 4 to 27 seconds to estimate. A chance order of presentation was used throughout the experiment. These intervals were unfilled time bounded by two telegraphic sounder clicks. The subjects were requested to estimate the length of the interval and report their estimates in seconds or fractions of a second. The subjects were directed to use no counting or other conscious rhythmical aids. The intervals were presented in series of ten with short rest periods between each series. One hundred estimates were made by each subject on each of two days. As each series of time intervals was presented to the subjects measurements of the five physiological functions mentioned above were made.

In a second part of the experiment the subjects were given vigorous exercise in running up and down steps in order to speed up the physiological functions. Immediately following the exercise another series of estimations and measurements were made in order to determine what effect, if any, the increased physiological functions would have on the estimation of time. One hundred additional records were taken for each subject on each of two days.

The Keeler polygraph with sphygmomanometer and pneumograph attachments was used for making continuous graphic records of all five physiological changes. This instrument gives reliable records for measuring heart rate, breathing rate and changes in blood pressure. Accurate records can also be made for changes in amplitude of pulse and breathing during any one sitting.

Fortunately in the present experiment all comparisons were to be made only between measurements taken during a single series of time estimates.

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The amplitude of the breathing records and heart beat were measured by means of an oscillometer.[18]

The time intervals for estimation were produced by means of a telegraphic sounder which was actuated by a key in a series with a seconds pendulum. An electric marker indicated the time signals on the polygraph paper simultaneously with the records of the physiological changes.

Four male college students were used for subjects. They were members of a class in general psychology. They gave excellent cooperation throughout a rather arduous series of sittings in which a high degree of attention was continuously necessary.

Errors were calculated in percent of over- or underestimation. Overestimation means that the subject judged the time to be longer than it actually was; underestimation means that it was judged shorter than it actually was. Graph I shows the average percent of error for each of the different time intervals for each of the four subjects. These results indicate that there is a somewhat greater percentage of underestimation of the longer intervals (22 and 27 seconds) than for the shorter intervals (4 and 6 seconds). The form of the curves is essentially the same both during rest and following exercise. In two subjects on one day each the amount of underestimation is greater after exercise than at rest. On the other two days and for the other two subjects there is no significant difference between rest and exercise.

There is no tendency toward a shift in over- or underestimation during any day. This is shown for all four subjects in Graph I.

The following table (Table I) presents the range and mean percent of over- and underestimation for each subject both at rest and after exercise. Overestimation is marked + and underestimation −.

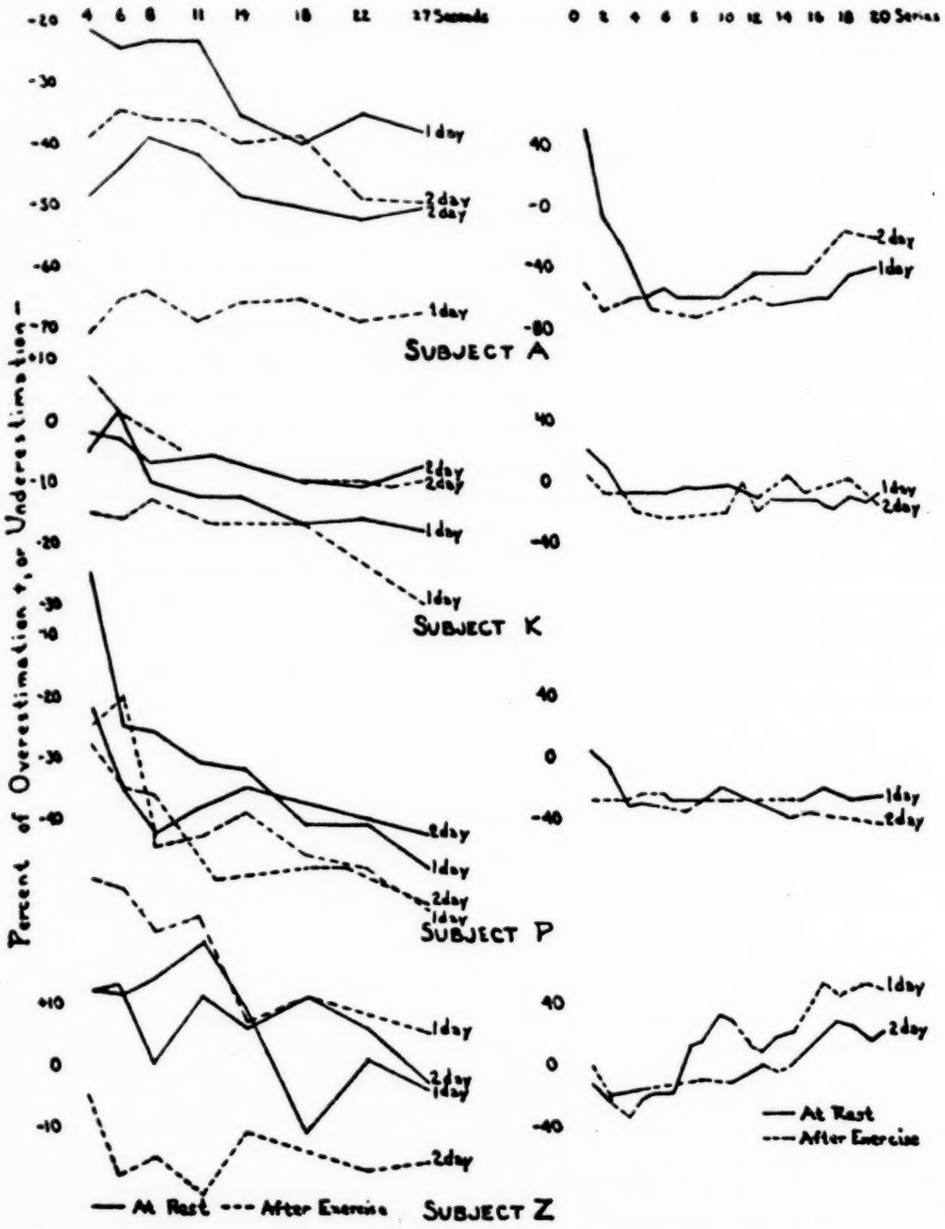
TABLE I

Subject	At Rest		After Exercise		C.R.
	Range	Mean	Range	Mean	
A	−79.9 to +128.0	−49.5	−84.9 to + 4.9	−57.0	1.56
K	−38.9 to + 35.9	− 9.1	−37.0 to +33.9	−12.8	.56
P	−67.0 to + 19.1	−28.4	−66.6 to +33.4	−32.5	.80
Z	−76.6 to + 93.3	+ 8.0	−66.6 to +83.3	+ 4.0	3.48

This table shows a wide range of error in estimation for each subject. It also shows a general tendency for three subjects to underestimate both at rest and after exercise while the other subject tended to overestimate in both cases.

Table II gives the range and means for (1) pulse rate per second, (2) heart work expressed in oscillometer units, (3) breathing rate per second, (4) lung work expressed in oscillom-

[18] Hull, C. L., An instrument for summating the oscillations of a line, *J. Exper. Psych.*, 1929, **12**, 359–361.



The physiological changes could also be expressed in terms of the amount of change per second. This made it possible to correlate each of these physiological changes directly with the errors of estimation.

eter units, and (5) blood pressure changes in oscillometer units. These are given both during time estimations at rest and after exercise.

These records also show wide changes in the functions measured during the estimations for each subject as well as wide variations between subjects.

TABLE II

RANGE AND MEANS FOR FIVE PHYSIOLOGICAL CHANGES DURING TIME ESTIMATIONS AT REST AND AFTER EXERCISE

At Rest

Subject	Pulse Rate		Heart Work		Breathing Rate		Lung Work		Blood Pressure	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
A	1.03–1.73	1.44	3–16	8.3	.12–.39	.30	.35– 5.0	1.77	– 3–15	4.0
K	1.20–2.02	1.73	12–35	25.7	.31–.50	.38	.25– 5.1	2.42	– 3–21	1.9
P	.48–1.65	1.34	12–26	19.5	.22–.64	.40	.45– 5.0	1.61	– 3–18	3.1
Z	1.35–1.95	1.71	4–29	15.8	.20–.49	.33	.13– 9.6	4.50	–37–10	2.5

After Exercise

A	1.00–2.20	1.62	4–40	17.5	.25–.42	.34	1.00–24.0	7.00	–22–17	1.7
K	1.30–2.50	1.81	11–42	24.1	.33–.63	.43	1.00–34.0	9.10	–24–18	3.1
P	1.25–2.10	1.62	16–42	27.1	.12–.60	.42	1.00–47.0	9.00	–17– 5	3.0
Z	1.00–2.40	1.99	8–59	23.2	.20–.52	.36	2.00–55.0	13.50	–37–37	2.2

Table III gives the Pearson coefficients of correlation between the five physiological functions measured and the time estimations both at rest and after exercise.

TABLE III

CORRELATION BETWEEN FIVE PHYSIOLOGICAL FUNCTIONS AND TIME ESTIMATION

At Rest

Subject	Pulse Rate		Heart Work		Breathing Rate		Lung Work		Blood Pressure	
	1 Day	2 Day	1 Day	2 Day	1 Day	2 Day	1 Day	2 Day	1 Day	2 Day
A	–23	–13	.34	–10	–.36	.07	–.24	–.32	.10	.27
K	–55	.05	.05	–.14	.22	–36	.25	.08	.50	.01
P	.31	.23	.00	.23	–.07	.33	.25	.19	.45	–.11
Z	.09	–07	.16	–.17	–.13	–21	–21	–.40	40	–06

After Exercise

A	.19	.37	–.23	–16	.43	–.16	.01	.33	.19	–.27
K	.28	–12	–.07	–03	.15	–05	.09	–.25	.06	.05
P	–08	–06	–.08	–.11	.06	.14	–.08	–.05	–.07	–.09
Z	–14	.06	–03	–.14	–.55	.55	–54	.09	.25	–.11

On examination of Table III, we find that of the 80

coefficients of correlation the highest in value is .552. Of these, only 25 r's stand Fisher's test for the least significant r; and only 16 are four times their probable error. Since all of the r's are small they ought to be more than four times the P.E. Only 11 r's are $4\frac{1}{4}$ times the probable error, and all of these are reversed in sign from the r for the same function under the same condition for the second of the two experimental days. Furthermore, the coefficients of correlation show no tendency to be constant in sign from one individual to another for the same condition on the same day. Thus all coefficients were low, most of then near zero, and wherever there were coefficients which tended to be significant they were reversed in sign on the second experimental day. It is very evident that there is no constant tendency for the estimation of short time intervals to vary with the changes in the physiological conditions studied.

If the estimation of time is related to the variables studied that relationship should be evident by the correlation technique. However, if the relationship is between estimation and the variables as an interdependent group, the correlation technique would not exhibit the relationship unless the whole group of factors could be changed at once. For this reason exercise was introduced. The error of estimation between rest and exercise conditions shows a significant difference for only one subject on one day. In all other cases, even when all of the physiological conditions were changed by as much as an increase of 50 percent as they were in most cases, the error of estimation did not change in direction or amount, nor was there any greater variation in the individual estimations than while in a condition of rest.

The critical ratios range from .125 to 4.40 with a median at .90; and five of the ratios are in favor of greater estimation and three in favor of lesser estimation at rest than after exercise.

It is evident then that the individual physiological variables have no constant relationship to the estimation of short time intervals; and also that there is no apparent constant

relationship of the variables studied, taken as a group, to the estimation of the short time intervals.

Since this investigation has shown that no relationship exists between time estimation and the five physiological changes studied, some other hypothesis must be used as an explanation. Another possibility is that bodily functions other than those studied form the basis for time estimation. Or it may be that time estimation is not dependent on any physiological function but that perception of short time intervals may be dependent upon many cues taken from the environment of the individual; that different cues serve for different individuals; and that the same individual may use different cues on various occasions without necessarily being aware of the basis of the perception in any given situation.

Summary and Conclusions

From this study the following conclusions may be drawn:

1. There is no significant relationship between the estimation short time intervals and the five physiological conditions studied in this investigation.

2. The general direction and amount of error in estimation of time remains approximately the same from one day to another. There is some tendency for the longer intervals to be underestimated more than the shorter intervals.

3. The physiological changes of heart work, pulse rate, blood pressure, lung work, and breathing rate as studied in this experiment vary greatly during the experiment.

4. What changes there are in individual estimations do not show any constant or definite relationship to changes in physiological conditions.

5. There is no significant difference in errors between estimations when the subject is resting and when the subject is in a state of great physiological activity. Thus, the physiological factors, here studied, as a group are not related to the estimation of short time intervals.

6. There is no tendency for all subjects to estimate time as being longer or shorter after long periods of continued estimation and fatiguing exercise.

Thus, since there is seemingly no definite relationship between the physiological factors studied and the amount or direction of error in the estimation of short intervals of time, the problem of time perception stands as a challenge to further investigation.

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ADAPTATION OF THE GALVANIC SKIN RESPONSE [1]

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In an article recently published in this JOURNAL, Coombs (1) reported the results of an investigation concerning the adaptation of the galvanic skin response to auditory stimuli. Among other things it was found that the adaptation of the response to repetitive stimulation was in part general to the stimuli within a given sense modality, and in part specific to the stimulus employed. The question is also raised concerning the possibility of the transfer of adaptation from one sense modality to another. Coombs' data afford no evidence on this question inasmuch as the stimuli which he employed were all auditory in nature.

Several years ago the writer conducted a short experiment in an attempt to determine the answer to this latter question, the results of which have not been previously presented. It was the object of this investigation to determine whether or not adapting the galvanic skin response by repetitive stimulation via one sense modality would have any effect upon the adaptation of the response to subsequent repetitive stimulation via a second sense modality.

The apparatus employed for measuring the galvanic skin response has been described by Davis and Porter (4). Non-polarizable electrodes, described by Davis (3, p. 29), were employed and were attached upon the palmar surface of each arm just posterior to the wrist bones.

Eight students from psychology classes, two women and six men, served as subjects.

A subject for the experiment was seated by himself in a dark room several rooms distant from the one in which the measuring apparatus was located. Light, save from that employed as a stimulus, was practically excluded, and though not sound-proof the room was relatively quiet. Two different modes of stimulation were employed, visual and auditory. The visual stimulus was supplied by a flash of light from a hun-

[1] This experiment was conducted in the Psychological Laboratory at the University of Virginia during the writer's tenure as Dupont Senior Research Fellow in Psychology.

dred watt electric light bulb mounted in front of a large reflector. This unit was mounted upon a stand which was placed about two and a half feet in front of the subject and in a plane only slightly below that of his eyes. An ordinary electric door-bell attached to a leg of the chair in which the subject was seated served as the auditory stimulus. Both the light and the bell were controlled by switches located in the recording room beside the measuring apparatus.

The procedure employed during the experimental periods was as follows. The subject was seated in front of the stand holding the electric light bulb and reflector, in the dark room. The electrodes were attached to the wrists firmly, yet not tight enough to interfere with circulation. He was warned against moving any part of his body any more than was necessary to prevent his becoming cramped, since such movements sometimes serve to stimulate the galvanic skin responses, and was requested to maintain, as near as possible, a constant fixation—straight ahead and in the plane of the light bulb which was to supply the visual stimulus. The nature of the two modes of stimulation to be employed was explained to the subject, but not the sequence of presentation. The electrodes attached, the door to the dark room was closed and a few seconds later the exsomatic current (0.1 milliampere) was turned on and allowed to flow for an interval of three minutes before the first stimulus was given, in order that the apparent skin resistance might reach a stable value. At the end of this period the first mode of stimulation was applied for three seconds and repeated for the same interval every thirty seconds until upon three successive occasions it failed to elicit the galvanic skin response. Three such successive trials were arbitrarily chosen as the criterion of complete adaptation. Upon the occasion of the third successive failure of the first mode of stimulation to elicit the response, without any signal to the subject, the second mode of stimulation was employed at like intervals until upon three successive presentations it failed to elicit the response. The order in which the two modes of stimulation were presented was varied in such a manner as to keep the subject in ignorance of which would be used first upon any particular day. Records were taken on each subject approximately every other day.

Results

A total of 52 records were obtained on this group of subjects, in approximately half of which the first mode of stimulation was visual and the second auditory; in the remainder the order of presentation was reversed (see Table I). Since the number of records obtained on each subject is not sufficiently large to justify extensive statistical treatment, the following method of analysis was adopted. The data were divided into two groups upon the basis of the first mode of stimulation employed. The difference between the number of stimulations required to secure adaptation to the first mode of stimulation and the number required to secure adaptation to the second mode of stimulation was regarded as indicative of the effect adaptation to the first mode of stimulation had had upon adaptation to the second. The data show that where

TABLE I

SHOWING THE NUMBER OF PRESENTATIONS OF STIMULI REQUIRED TO SECURE COMPLETE ADAPTATION OF THE GALVANIC SKIN RESPONSE (SEE TEXT FOR DEFINITION OF COMPLETE ADAPTATION)

The letter in parenthesis following each value in the table indicates the nature of the stimulus employed, *i.e.*, (A) auditory; (V) visual.

Subject	1st Exp. Session	2nd Exp. Session	3rd Exp. Session	4th Exp. Session	5th Exp. Session	6th Exp. Session	7th Exp. Session
Sol.	8(A) 8(V)	10(V) 5(A)	4(V) 4(A)	4(A) 3(V)	10(V) 7(A)		
Eva.	6(V) 6(A)	4(A) 4(V)	8(V) 8(A)	4(V) 4(A)	9(A) 7(V)	5(A) 5(V)	
Win.	48(V) 4(A)	32(A) 4(V)	25(V) 5(A)	6(A) 5(V)	18(V) 5(A)	8(V) 4(A)	
Wor.	13(A) 5(V)	8(V) 5(A)	9(A) 4(V)	4(V) 8(A)	10(A) 4(V)	19(V) 20(A)	42(V) 19(A)
Spe.	9(V) 4(A)	12(A) 4(V)	11(V) 4(A)	11(A) 18(V)	15(A) 10(V)	8(A) 3(V)	5(V) 4(A)
Gil.	9(A) 4(V)	5(V) 4(A)	3(V) 4(A)	4(V) 4(A)	4(A) 15(V)	11(V) 4(A)	4(A) 5(V)
Ger.	3(A) 3(V)	3(V) 3(A)	4(A) 4(V)	8(V) 12(A)	6(A) 4(V)	4(A) 3(V)	7(V) 3(A)
Ros.	6(V) 4(A)	3(A) 3(V)	3(V) 3(A)	5(V) 4(A)	4(A) 3(V)	3(A) 3(V)	6(V) 5(A)

the first mode of stimulation was visual and the second auditory it required on the average 1.74 more presentations of the stimulus to fatigue the response to the first mode of stimulation than it did to the second. While this is not a significant difference (D/σ diff. = 2.32), the chances are 99 in 100 that the true difference is greater than zero. In those instances in which the first mode of stimulation was auditory and the second visual it required on an average 1.1 more presentations of the first stimulus than of the second to fatigue the response. This difference, also, is not a significant one (D/σ diff. = 1.30) but the chances are 90 in 100 that the true difference is greater than zero. Though these differences are not reliable they imply that the adaptation of the galvanic skin response to one stimulus exercises an effect upon the adaptation of the response to immediately subsequent stimuli. The fact that

it required more presentations of the first stimulus to fatigue the response when that stimulus was visual in nature is, in the investigator's opinion, to be regarded as an artifact of the experimental situation more than anything else. It was possible to exclude practically all light from the room in which the subject was seated, but it was impossible to exclude certain extraneous noises, hence the apparent efficacy of the visual over the auditory stimulus is probably explainable in terms of the background against which the stimuli were administered.

Since the experimental situation became more or less familiar to the subjects as time passed, and as familiarity would tend to decrease the subject's reactivity to stimulation, it is worthwhile examining the results obtained during the first and last experimental periods with each subject. Examination of these first eight records reveals that it required on the average 3.6 more presentations of the first stimulus than of the second, regardless of its nature, to fatigue the response, while examination of the last eight records shows that this difference has diminished to 1.25 presentations. Intermediate records exhibit in general a gradual diminishing of this difference.

A phenomenon comparable to disinhibition in the Pavlovian sense was observed upon several occasions. During several experimental periods it happened that after the subject had failed to respond to one or two presentations of the stimulus he received some form of extraneous stimulation such as the noise made by people walking by the door, or conversing in the corridor near the door to the subject's room. In such instances, almost without fail, the subject would respond to these extraneous stimuli and upon the next presentation of the mode of stimulation then being employed would respond and continue to do so for several minutes. It was decided that such records should not be included in the data of this investigation. Obviously, however, the effect upon the galvanic skin response of interpolating unexpected stimuli during the progress of a known series is one that should be investigated. Davis (**2**, p. 44) has reported that in instances in which the subject fails to respond to a familiar stimulus,

the interpolation of another mode of stimulation will have a facilitating effect upon the response to the familiar stimulus.

These data suggest the following conclusions:

1. When the galvanic skin response is adapted to one mode of stimulation the number of presentations of a second, and immediately subsequent, mode of stimulation necessary to secure the adaptation of the response is appreciably diminished. Transference of adaptation is indicated.

2. The number of stimulations required to secure adaptation of the response tends to decrease during successive experimental sessions.

In addition it was indicated that interpolation of unfamiliar stimuli during the presentation of a series of familiar stimuli acts to facilitate (or disinhibit) the diminishing response to the familiar stimulus.

(Manuscript received May 27, 1938)

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